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July 1995

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Waterways Experiment Station

LEVSEEP: Analysis Software for Levee Underseepage and Rehabilitation

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Prepared for Headquarters, U.S. Army Corps of Engineers

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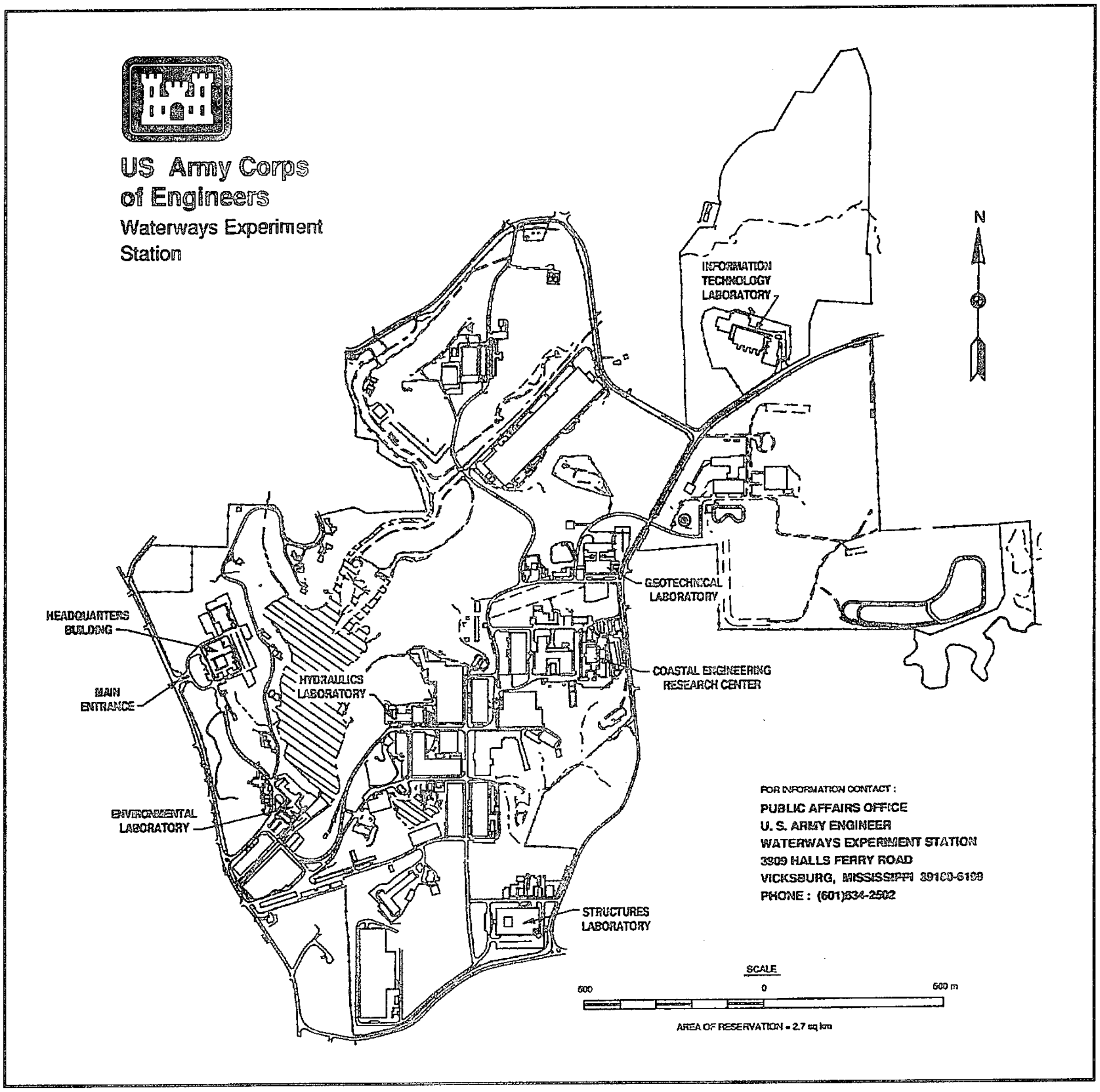

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Preface

This report uses the computer software LEVSEEP to describe analysis methodology for levee underseepage analyses and rehabilitation. Information required for data input, calculation procedures, output, and graphics is presented. In addition, comprehensive results of case studies and parameter analyses utilizing LEVSEEP are included. Several appendices present example problems illustrating input data files, calculations, graphics output, and summaries. This report supplements and extends the work of U.S. Army Engineer Waterways Experiment Station (WES) Technical Report REMR-GT-13 (Cunny, Agostinelli, and Taylor 1989).

Funding for improvements of the program came from Headquarters, U.S. Army Corps of Engineers (HQUSACE), and from the Huntington District for the Magnolia, Ohio, levee case study. Funding from the HQUSACE was provided to make program improvements, corrections, modifications, and documentation under the Numerical Model Maintenance Program.

Work described in this report was performed by Mr. Anthony L. Brizendine of Fairmont State College, Dr. M. A. Gabr of West Virginia University, and Mr. Hugh M. Taylor, Jr., Soil Mechanics Branch (SMB), Soil and Rock Mechanics Division (S&RMD), Geotechnical Laboratory (GL). Mr. W. L. Hanks, SMB, provided automated drafting support. Conversion to the Microsoft QuickBASIC (TM) language was performed by Mr. M. K. Sharp, Engineering Geophysics Branch, Earthquake Engineering and Geosciences Division, GL.

This work was performed under the direct supervision of Mr. William M. Myers, Chief, SMB. General supervision was provided by Dr. Don C. Banks, Chief, S&RMD, and Dr. William F. Marcuson III, Director, GL.

During the preparation and publication of this report the Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement can be converted to SI units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
gallons (US liquid) per minute	0.000006309	cubic meter per second
inches	2.54	centimeters
miles (U.S. statute)	1.609347	kilometers
square inches	6.4516	square centimeters

Summary

Levees are earth structures constructed to provide flood protection during and after high-water events. A major concern associated with these levees is the underseepage through the foundations on which these levees are constructed. Levee underseepage was identified by field personnel of the Army Corps of Engineers to be one of the high-priority soils-related problems to be addressed in the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program (Scanlon et al. 1983). The computer programs LEVSEEP and LEVEEMSU were developed as part of the approach to facilitate analyses of levee underseepage and to assist in the evaluation of inconsistencies between predicted and actual levee performance.

Subsurface conditions beneath levees in alluvial valleys are traditionally modeled as two soil layers, a semipervious top blanket or top stratum of clay, silt, or silty sand overlying a pervious substratum of sand. High-water conditions riverside of the levee result in downward flow of seepage through the riverside top blanket, lateral flow through the pervious substratum, and upward flow through the landside top blanket. Given certain conditions of geometry and soil properties, the upward gradient in the landside top blanket can be excessive, and safety against excess hydrostatic pressure is of concern. Underseepage analyses are performed to predict the piezometric head at the base of the landside top blanket (at the levee toe) and the gradient through the blanket (at the landside levee toe) as functions of riverside and landside water levels. Where calculations indicate that excessive gradients are expected, underseepage control measures may be required. These measures are typically landside seepage berms, riverside blankets, cutoffs, or relief wells. Analyses to assess the effect of one or more proposed or existing control measures may also be performed with LEVSEEP.

This program calculates seepage flow and substratum pressure for either physical and geometric properties (initial conditions) or field piezometer readings. It also calculates the effect of various control measures on seepage flow and substratum pressure for those cases for which published Corps procedures exist. These control measures include landside berms, riverside blankets, cutoffs, and relief wells. LEVSEEP also provides quantity and cost estimates for the respective control measures. The procedures for berm analysis employed within LEVSEEP reflect the current Corps guidance as

given in EM 1110-2-1913 (Headquarters, Department of the Army 1978). The procedures for riverside blanket analysis are presented in TM 3-424 (U.S. Army Engineer Waterways Experiment Station 1956). Procedures for analysis of cutoffs are based on the method of fragments as presented by Harr (1962). The procedures for relief well system analysis reflect Corps guidance as given in EM 1110-2-1914 (Headquarters, Department of the Army 1992). Specific equations and procedures used for well analysis were taken from TM 3-424 and Engineer Bulletin 55-11 (Headquarters, Department of the Army 1955). The well procedure is for infinite, partially penetrating, or fully penetrating well systems under artisan flow; it does not apply to finite length systems or pumped systems. A solution for the piezometric head beneath a semipervious top blanket adjacent to a dam or levee on a pervious substratum was proposed by Bennett (1946). Bennett assumed perfectly horizontal flow in the pervious substratum and perfectly vertical flow in the top blanket. If the thicknesses and permeabilities of the blanket and the substratum are taken as constants, the piezometric head at the base of the blanket and the upward gradient through the blanket can be directly calculated for a number of various boundary conditions, using equations. Solutions have been widely published within the Corps of Engineers (U.S. Army Engineer Waterways Experiment Station 1956; Headquarters, Department of the Army 1978) and elsewhere (Turnbull and Mansur 1961a,b). Underseepage analysis by the Corps traditionally has utilized these closed-form solutions. The models developed in the aforementioned Corps publications and incorporated into LEVSEEP make basic assumptions that must be recognized. Those assumptions are as follows:

a. Seepage may enter the pervious substratum at any point in the foreshore (usually at the riverside borrow pit) and/or through the riverside top stratum.

b. Flow through the top stratum is vertical.

c. Flow through the pervious foundation is horizontal.

d. The levee (including impervious or thick berms) and the portion of the top stratum beneath it are impervious.

e. All seepage is laminar.

The program is furnished as a binary executable file, LEVSEEP.EXE, designed to run on IBM (trademark or TM) and compatible personal computers under the MS DOS (Microsoft Corporation 1983) operating system. A math coprocessor is not required for execution, but is recommended. No computer language or compiler needs to be installed on the computer. The program was developed with the use of Microsoft QuickBASIC (TM)(1986) and linked to required library files to produce a single executable file. The program reads input data from either an interactive mode or a separate data file. The program displays default values for many input variables within the program. These values can be changed from the keyboard during program

execution. Results of the analysis can be displayed on the graphic screen or sent to a plotter. A detailed summary of the results is written to an output file which can be printed either during program execution or separately afterward.

To begin execution of the program, the user needs only to insert the disk and type LEVSEEP, followed by the enter key. The program will initialize, and the user will see the main menu. The user may access one of the included example files using the load file command. Simply indicate the file name (i.e., cross6), and that file will be loaded into the program. The user may then access the input/edit screens to view the data. The user may access the display option to create a graphic of the geometry of the example problem. Calculations for initial conditions and control measures (i.e., riverside blanket, landside berm, cutoffs, and relief wells) may be performed by the selection of the respective options under the calculations menu heading. A summary of all calculations may be accessed, printed, or saved by the summary option being accessed. A complete description of all these options is included in Chapter 3 of this manual.

The new graphics and editing capabilities of version 3.0 of the program are described in-depth in this report. A program description is presented in Chapter 2 of this report where solution techniques, seepage calculations, and control measures of the program are discussed. Program execution is described and illustrated in Chapter 3. Menus and submenus are also presented in this chapter. Chapter 4 presents the results of analyses of idealized levee sections at Magnolia Levee, Ohio. Chapter 5 presents the design applications, while Chapter 6 defines the limitations of the program. Chapter 7 offers conclusions and recommendations associated with the project. Appendix A presents an interactive example for the benefit of the user. Appendices B, C, and D offer additional examples based on case studies. Appendix E contains information on the default unit cost of the various control measures. Appendix F provides a history of the evolution of LEVSEEP. Appendix G is the Notation which lists symbols and abbreviations.

Magnolia Levee, located in the Huntington District, was selected as a case study to demonstrate the applicability of LEVSEEP for parameter studies. The analyses of this case study yielded results that emphasized the importance of accurate characterization of the foundation sublayers. The selected lengths of the top blanket riverside and landside of the levee significantly impact the predicted gradients. Predictions of exit gradients and hydraulic heads reasonably matched measured data.

LEVSEEP provides a convenient analysis tool that should allow designers to approximately model most field conditions. However, flood protection is a complex system involving design, construction, maintenance, and performance evaluation of levees. The use of LEVSEEP can provide flexibility in exploring the influence of varying key analysis parameters on the predicted results and can be used to reevaluate design criteria with the possible benefit of reducing cost and improving safety.

1 Introduction

Background on Levees and Underseepage

Levees are earth structures constructed to provide flood protection during and after high-water events. While levees were originally utilized for the protection of agricultural land from floodwater, their use for flood protection of industrial, commercial, and residential facilities has been increasing over the past two decades. A major concern associated with these levees is the underseepage through the foundations on which these levees are constructed. In situations where flood-control levees are constructed on pervious foundations, seepage beneath a given levee can result in failure during flood periods. Such a failure can develop because of excessive uplift pressures, piping, and subsurface erosion.

In general, most of the Corps' criteria for the design of levees was developed in the 1940's and 1950's. There has been an emerging concern that Corps procedures and criteria may be overly conservative in many cases and unconservative in others. Overconservative designs may necessitate the implementation of costly control measures where they may not be needed. Unconservative designs are usually evidenced through the failure of analysis to predict excess gradients at locations where sand boils and erosion may occur and cause damage.

Levee underseepage was identified by field personnel of the U.S. Army Corps of Engineers to be one of the high-priority soils-related problems to be addressed in the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program (Scanlon et al. 1983). A Levee Underseepage Workshop for the REMR program was held at the U.S. Army Corps of Engineers, Waterways Experiment Station (WES), on 10 April 1984 to establish research needs related to levee underseepage control. Representatives from the Rock Island, St. Louis, Memphis, and Vicksburg Corps of Engineers Districts attended. One research task identified was comparing predicted levee underseepage conditions to observed performance. Data collected in the past two decades on the performance of levees during major flood events were used for this purpose.

A review of underseepage analysis procedures was prepared by Wolff (1986). Wolff noted that the Corps analysis and design procedures required a high level of judgment to formulate geometric and geologic conditions. In particular, while actual soil profiles and topography were often irregular, current Corps manual procedures required idealized, horizontally leveled topography with uniform thicknesses of the soil layers. While one very important aspect of the levee design involves the development of an accurate characterization of the site conditions, it is very common for two designers to arrive at different characterizations when given the same boring logs. While the design process was driven by the variables such as blanket thickness (z) and blanket permeability (k_b), interpretations by two designers of the values of z and k_b will not necessarily be equivalent.

The computer programs LEVSEEP and LEVEEMSU were developed as part of the approach to facilitate analyses of levee underseepage and to assist in the evaluation of inconsistencies between predicted and actual levee performance.

This report was developed in part as a user's manual for the upgraded version 3.0 of the computer program LEVSEEP. Version 3.0 of the program provides a much more user-friendly environment, offers full screen editing capabilities, and affords dramatically improved graphics capabilities. This version of the program includes a two-layer analysis model for levees with a top blanket over a pervious foundation. The solution algorithm implemented in the program is based on the modeling of the flow domain with analytical solutions for underseepage and the method of fragments solution for cutoff analyses. Example problems and case studies are presented for instruction and verification of the computer model. Development, testing, and use of the program are presented in this manual through example problems and case studies.

Previous Studies

Investigation of potential levee underseepage was initiated in 1937 by the Mississippi River Commission (MRC) in response to problems caused by high-water conditions. A study was carried out by WES in the 1940's to investigate causes of underseepage and sand boils along the lower Mississippi River levees. Possible methods of evaluating the quantity of underseepage, uplift pressures, and hydraulic gradients were developed. In addition, possible control measures have been identified and investigated. The developed procedures were based on closed-form solutions for differential equations of seepage flow presented by Bennett (1946).

Technical Memorandum (TM) 3-424 by U.S. Army Engineer Waterways Experiment Station (1956) documented the analysis of underseepage and design of control measures for the Lower Mississippi Valley (LMV) levees. The developed analysis procedure provided means for the evaluation of the residual head (h_o) at the landside levee toe. The general geology of a typical

levee in the LMV included a relatively thin layer of low permeability soil, referred to as the top blanket, underlain by pervious soil, referred to as the foundation. The critical hydraulic gradient for levees at that location, designated as the exit hydraulic gradient, was estimated by dividing h_o by the thickness of the top blanket. Parameters needed for the estimation of the exit hydraulic gradient included the riverside and landside water elevations, the levee geometry, and the geometrical and geological characterization of the subsurface strata. It was assumed that underseepage control measures were needed if the exit hydraulic gradient exceeded an allowable value (typically assumed to be 0.85).

In the same TM 3-424 a detailed discussion was presented on the surficial floodplain geology and its relationship to underseepage and occurrence of soil boils. Design and analyses procedures presented in TM 3-424 were summarized by Turnbull and Mansur (1961a,b). Engineer Manual (EM) 1110-2-1913 for the Design and Construction of Levees (Headquarters, Department of the Army 1978) included the design procedures presented in the TM 3-424.

Wolff (1974) and the U.S. Army Engineer District, St. Louis (1976) reviewed the performance of the Alton-to-Gale levee system, located along the middle Mississippi River, during the record flood of 1973. It was concluded in the report by the St. Louis District (1976) that the use of the Corps procedure resulted in a reliable design of the levee. However, several areas were identified where the existing procedure proved deficient. These areas included the inaccurate two-layer characterization of the subsurface profile and the inability to model levee bends at corners.

A comprehensive report summarizing data from 29 piezometer ranges and as many as 9 high-water periods was presented by Cunny (1980) for levees in the Rock Island District. In this study, Cunny implied that the probability of the occurrence of boils increases in locations of geologic discontinuities.

Daniel (1985) reviewed Cunny's report and other Rock Island data. He observed that, although the analysis suggested initiation of boiling at gradient of about 0.85, boils were observed to occur at gradients ranging from 0.54 to 1.02. Similar observation was noted as early as 1952 and presented in TM 3-424. Recommendations by Daniel included, among others, the development of a relatively sophisticated computer program to replace the existing method of analysis.

In cases where excessive exit gradients are predicted, remedial measures are designed and implemented. The most common remedial measures include pressure relief wells, landside seepage berms, riverside blankets, and cutoffs beneath the levees. Muskat (1937) presented a design methodology for relief wells as a remedial measure for levees with critical hydraulic stability. Middlebrooks and Jervis (1947) adjusted Muskat's method to account for the partial penetration of the relief wells. Barron (1948) presented a procedure

for analyzing fully penetrating relief wells with the assumption of leakage through the top blanket. A methodology was presented in Civil Works Engineer Bulletin 55-11 (Headquarters, Department of the Army 1955), whereby partially penetrating wells with a leaky top blanket were modeled. EM 1110-2-1905 (Headquarters, Department of the Army 1963) provided design tables for finite lines of relief wells based on electrical analog model studies.

Procedures for the design of seepage berms were presented in TM 3-424. These procedures addressed situations where the berm permeability is equal to or less than the top blanket permeability. Barron (1947) presented a design methodology for impervious, semipervious, and pervious berms. Modification to this design methodology was later performed by Barron (1984), and a procedure by which short berms are designed such that boiling is allowed to develop some distance from the levee toe was presented. Cunny's (1980) study on Rock Island levees concluded that existing criteria for design of berms for increased hydraulic stability are conservative. Required seepage berm widths based on observed data were smaller than those estimated using the existing criteria.

Research regarding the application of numerical methods to levee underseepage analysis was conducted by Wolff (1987). It was shown that the use of special-purpose computer programs had certain advantages over both traditional underseepage analysis procedures and general-purpose numerical seepage analysis programs. As previously noted, traditional procedures (U.S. Army Engineer Waterways Experiment Station 1956) required that subsurface stratum, ground and water elevations, etc., be modeled with uniform thicknesses and depths. It is often the case that these parameters assume different values at different points in a given cross section.

While general-purpose seepage analysis programs using, for example, the finite element method (e.g., Tracy 1973) can model such irregularities, they are often expensive to use and require a relatively high degree of effort to model a problem and interpret the results. In addition, information from conventional field investigations and engineering characterization of the subsurface soils are usually not sufficient to synthesize input parameters for the finite element model. For example, performing a two-dimensional finite element analysis would require data on the anisotropic permeability behavior of the soil. Such data are not available from traditional testing programs for site characterizations.

The research by Wolff (1987) included the development of "preliminary" programs to demonstrate the feasibility of the use of simplified numerical approaches for the analysis of levee underseepage. Three FORTRAN codes were developed including: LEVEEIRR, to model irregular geometry; LEVEE3L, to model three-layer foundations; and LEVEECOR, to model corners or bends in levee alignment. To achieve the development of these programs the finite difference method with a simplified representation of the flow domain was used. Wolff (1989) developed the computer program

LEVEEMSU for analysis of levee underseepage as a modified version of LEVEEIRR described above. This program was developed using BASIC code and included a number of Input/Output (I/O) and graphic enhancements. As presented by Wolff (1989), LEVEEMSU was used to analyze actual data at a number of levee reaches and back-calculate field permeability values. Wolff and Taylor (1991) extended the capabilities of the analysis scheme implemented in LEVEEMSU so that cases with a three-layer irregular foundation could be analyzed.

Early in 1985, Corps field personnel indicated a specific need for a microcomputer-based analytic tool for use in analyzing control measures, namely landside berms, riverside blankets, cutoffs, and relief wells. In 1985, Cunny, Mlakar, and Agostinelli completed work on two programs to calculate landside berms, riverside blankets, and cutoff control measures, as well as costs of each measure. The programs CONTROL and COST were the result of this work.

JAYCOR (Shockley et al. 1986) completed work in 1986 to calculate relief well control measures and associated costs of construction. JAYCOR was contracted in 1987 to combine the previous works into one and to incorporate various editorial and technical items as reported by Cunny, Agostinelli, and Taylor (1989).

Cunny, Agostinelli, and Taylor (1989) developed the computer program LEVSEEP to facilitate the analysis of levee underseepage and to assist in the evaluation of inconsistencies between predicted and actual levee performance. LEVSEEP allowed the user to obtain consistent results to levee underseepage problems in an expeditious manner. LEVSEEP performed calculations for reduced quantities of seepage because of control measures supported by the program. These control measures included landside berms, riverside blankets, cutoffs, and relief wells. LEVSEEP also provided quantity and cost estimates for the respective control measures. Also included were graphics to provide an instantaneous "view" of the levee and associated control measures. This new program "LEVSEEP" was a compilation of the previous work by JAYCOR.

While LEVSEEP proved to be a valuable tool in levee underseepage analysis, the program also established itself to be an imposing figure in terms of data entry and user-friendliness. This report and user's manual describe the program improvements relating to the user-friendliness, editing capability, and graphics of the program.

Scope

The scope of this project was to evaluate the analysis methodology for levee underseepage analyses and rehabilitation using the computer software LEVSEEP. LEVSEEP was first converted from Fortran (trademark or TM) (Microsoft Corporation 1984) to the MicroSoft QuickBASIC (TM)(1986) language. The graphics capabilities were upgraded and full screen editing was

incorporated. The user-friendliness and stability of the program were addressed and improved. Parameter studies from a case history at Magnolia Levee, Ohio, were conducted, and the results are included in this report.

This report will also serve as a user's manual and guide for version 3.0 of the computer program LEVSEEP. The new graphics and editing capabilities of version 3.0 of the program are described in-depth in this report. A program description is presented in Chapter 2 of this report where solution techniques, capabilities, and limitations of the program are discussed. Program execution is described and illustrated in detail in Chapter 3. Menus and submenus are also presented in this section. Chapter 4 presents the results of a case study of Magnolia Levee, Ohio. Design applications are discussed in Chapter 5 and program limitations are outlined in Chapter 6. Chapter 7 offers conclusions and recommendations associated with this project. Appendix A presents an interactive example for the benefit of the user. Appendixes B, C, and D offer additional examples based on case studies. Appendix E contains information on the default unit cost of the various control measures. Appendix F provides a history of the evolution of LEVSEEP. Appendix G is the Notation which lists symbols and abbreviations.

LEVSEEP provides the user with similar analyses to the hand methods of analysis outlined in EM 1110-2-1913, TM 3-424, EM 1110-2-1602 (Headquarters, Department of the Army 1980), and Engineer Bulletin 55-11. Additionally, graphic output provides a visual representation of the problem being analyzed while versatility for adequate representation of the problem is maintained. Rapid solutions on inexpensive computer hardware with minimal memory requirements can be obtained with virtually no chance of error in calculation. Likewise, output results are provided in meaningful format (e.g., gradient through the top blanket versus distance). A complete summary of all calculations may be printed for each analysis. This summary includes initial conditions, each control measure that is analyzed, and a cost summary for the various control measures analyzed.

2 Program Description and Summary

Program Description

The computer program LEVSEEP was developed to provide an efficient and reproducible means of analyzing levee underseepage. The ability to evaluate underseepage control measures was incorporated into LEVSEEP, as was the capability for estimating material quantities and cost. Version 3.0 has significantly improved editing and graphics capabilities as well as a much improved user-friendly format. A complete history of the evolution of the program is included in Appendix F.

The program is furnished as a binary executable file, LEVSEEP.EXE, designed to run on IBM (TM) and compatible personal computers under the MS DOS (Microsoft Corporation 1983) operating system. A math coprocessor is not required for execution but is recommended. No computer language or compiler needs be installed on the computer. The program was developed using Microsoft QuickBASIC (TM) and linked to required library files to produce a single executable file. The QuickBASIC language was selected in lieu of the more traditional FORTRAN to maximize the use of color and graphics capabilities of microcomputers and yet retain the mathematics of the source code in a form that is reasonably readable to engineering programmers. The program can be run in three graphics modes, EGA color, EGA monochrome, and CGA monochrome, depending on the available graphics card, monitor, and whether a graphics screen copy is desired. In the EGA and VGA color mode, the geometry of the substratum, top stratum, water, and piezometric grade line are displayed in color. In the VGA, EGA, and CGA monochrome mode, these factors are displayed in high-resolution and medium-resolution monochrome, respectively. In the monochrome modes, the graphic screen can be copied to a graphics printer with a screen dump program such as GRAPHICS.COM for CGA and EPSON.COM for EGA.

The program reads input data from either an interactive mode or a separate data file. The format of the input file is described in Appendix B. The program displays default values for many input variables within the program.

These values can be changed from the keyboard during program execution. Results of the analysis can be displayed on the graphic screen, and a detailed summary of the results is written to an output file which can be printed either during program execution or separately afterward. Details on running the program are described in Chapter 3. Example runs are shown in Appendixes A through D. Standard input data files are discussed in Chapter 3 and listed in Appendixes B, C, and D.

Solution Techniques

Subsurface conditions beneath levees in alluvial valleys are traditionally modeled as two soil layers: a semipervious top blanket or top stratum of clay, silt, or silty sand overlying a pervious substratum of sand. High-water conditions riverside of the levee result in downward flow of seepage through the riverside top blanket, lateral flow through the pervious substratum, and upward flow through the landside top blanket. Given certain conditions of geometry and soil properties, the upward gradient in the landside top blanket can be excessive, and safety against uplift and sand boils are of concern. Underseepage analyses are performed to predict the piezometric head along the base of the landside top blanket and the gradient through the blanket as functions of riverside and landside water levels. Where calculations indicate that excessive gradients are expected, control measures may be required. These measures are typically landside seepage berms, riverside blankets, cutoffs, or relief wells. Analyses to assess the effect of one or more proposed or existing control measures may also be performed with LEVSEEP.

A solution for the piezometric head beneath a semipervious top blanket adjacent to a dam or levee on a pervious substratum was proposed by Bennett (1946). Bennett assumed perfectly horizontal flow in the pervious substratum and perfectly vertical flow in the top blanket. If the thicknesses and permeabilities of the blanket and the substratum are taken as constants, the piezometric head at the base of the blanket and the upward gradient through the blanket can be directly calculated for a number of various boundary conditions using equations. Solutions have been widely published within the Corps of Engineers (U.S. Army Engineer Waterways Experiment Station 1956; Headquarters, Department of the Army 1978, 1986) and elsewhere (Turnbull and Mansur 1961a,b). Underseepage analysis by the Corps traditionally has utilized these closed-form solutions. The models developed in Corps publications and incorporated into LEVSEEP make basic assumptions that must be recognized. Those assumptions are as follows:

a. Seepage may enter the pervious substratum at any point in the foreshore (usually at the riverside borrow pit) and/or through the riverside top stratum.

b. Flow through the top stratum is vertical.

c. Flow through the pervious foundation is horizontal.

d. The levee (including impervious or thick berms) and the portion of the top stratum beneath it are impervious.

e. All seepage is laminar.

Reduced quantities of seepage where cutoffs are employed can be calculated according to Harr's (1962) method of fragments.

The procedures for berm analysis employed within LEVSEEP reflect the current Corps guidance as given in EM 1110-2-1913. The procedures for riverside blanket analysis are as presented in TM 3-424. Procedures for analysis of cutoffs are based on the method of fragments as presented by Harr (1962). The procedures for relief well system analysis reflect Corps guidance as discussed in EM 1110-2-1914 (Headquarters, Department of the Army 1992). Specific equations and procedures used for well analysis were taken from TM 3-424 and Engineer Bulletin 55-11. The well procedure is for an infinitely long row of equally spaced, partially penetrating or fully penetrating wells under artisan flow; it does not apply to finite length systems or pumped systems. Special features for the various analyses are described in the following section. A menu hierarchy for the program is included in Figure 1. The notations which follow those in EM 1110-2-1913 are consistently employed throughout this program and are conveniently defined in alphabetical order in Appendix G. Supplemental computer notations are also included with this listing. LEVSEEP contains a main menu with five major headings. Each of those main menu headings has several options. Each of those headings and submenus are discussed in detail in Chapter 3 of this manual. Some general comments on the program and its basis of operation are made here.

Seepage Calculations

This program calculates seepage flow and substratum pressure for either physical and geometric properties (initial conditions) or field piezometer readings. It also calculates the effect of various control measures on seepage flow and substratum pressure for those cases for which published Corps procedures exist.

When initial conditions from physical and geometric properties are calculated, nine distinct cases based on top stratum conditions are available; the first seven are described in EM 1110-2-1913 and the last two are combinations of semipervious and impervious landside and riverside top stratum added for completeness. A listing of those nine cases is as follows:

a. *Case No. 1.* No top stratum.

b. *Case No. 2.* Impervious top stratum both riverside and landside.

(1)

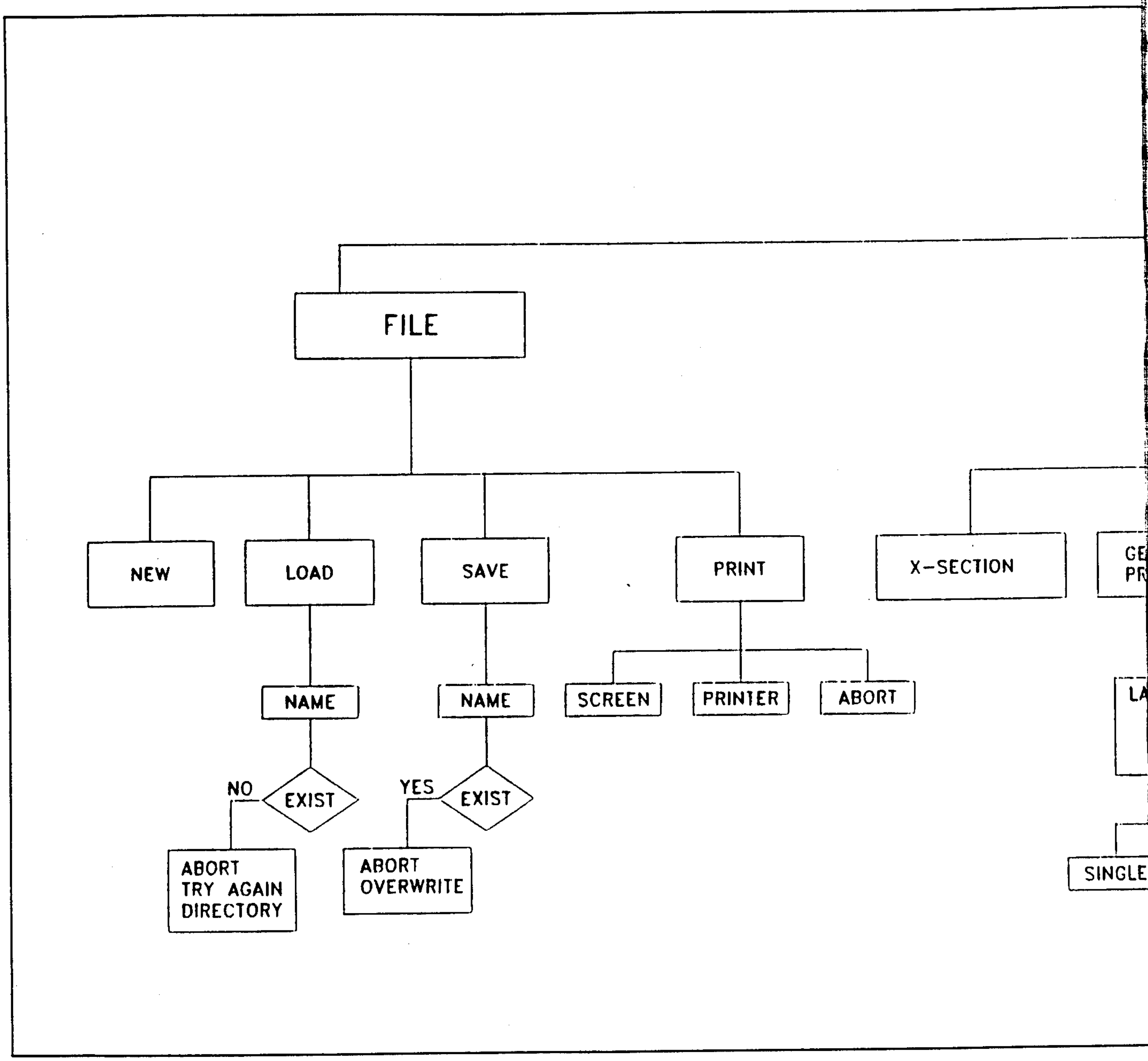

Figure 1. Simplified LEVSEEP menu hierarchy

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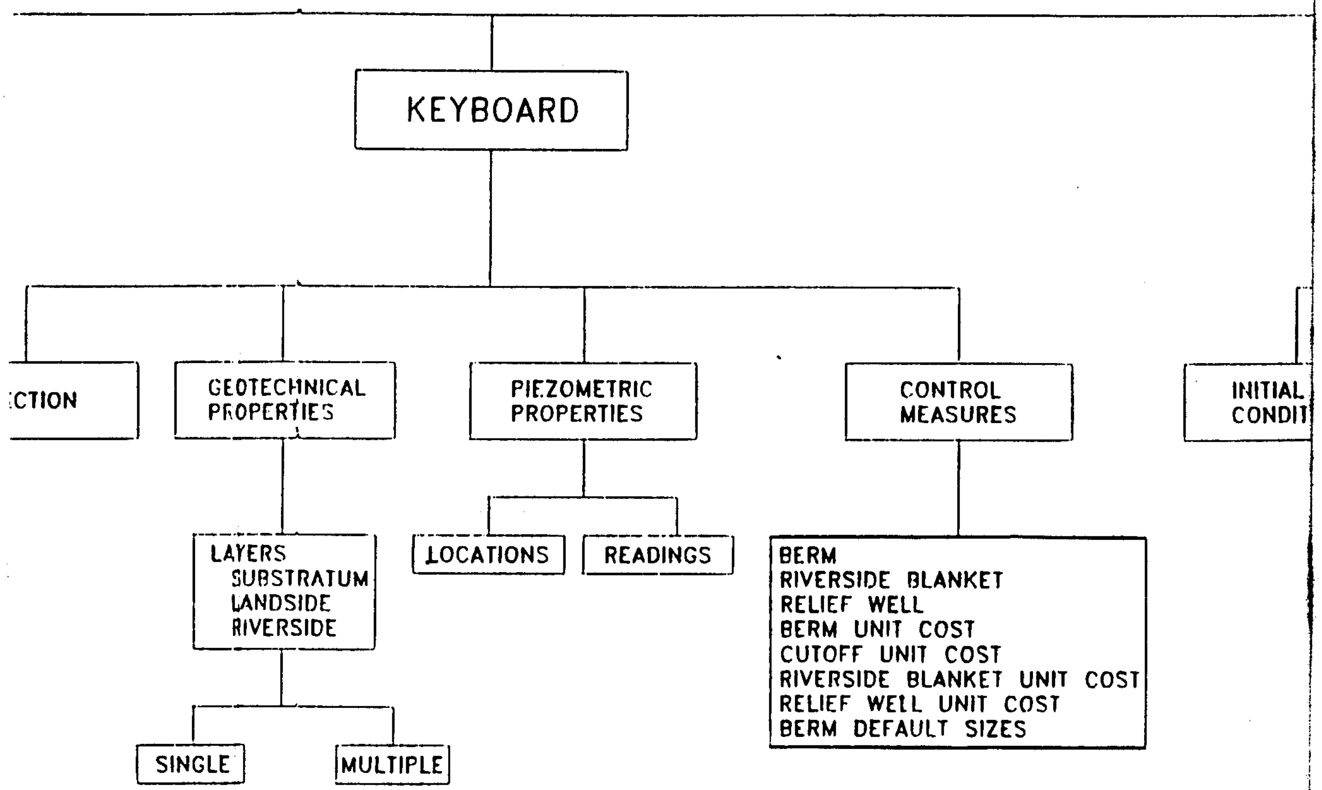
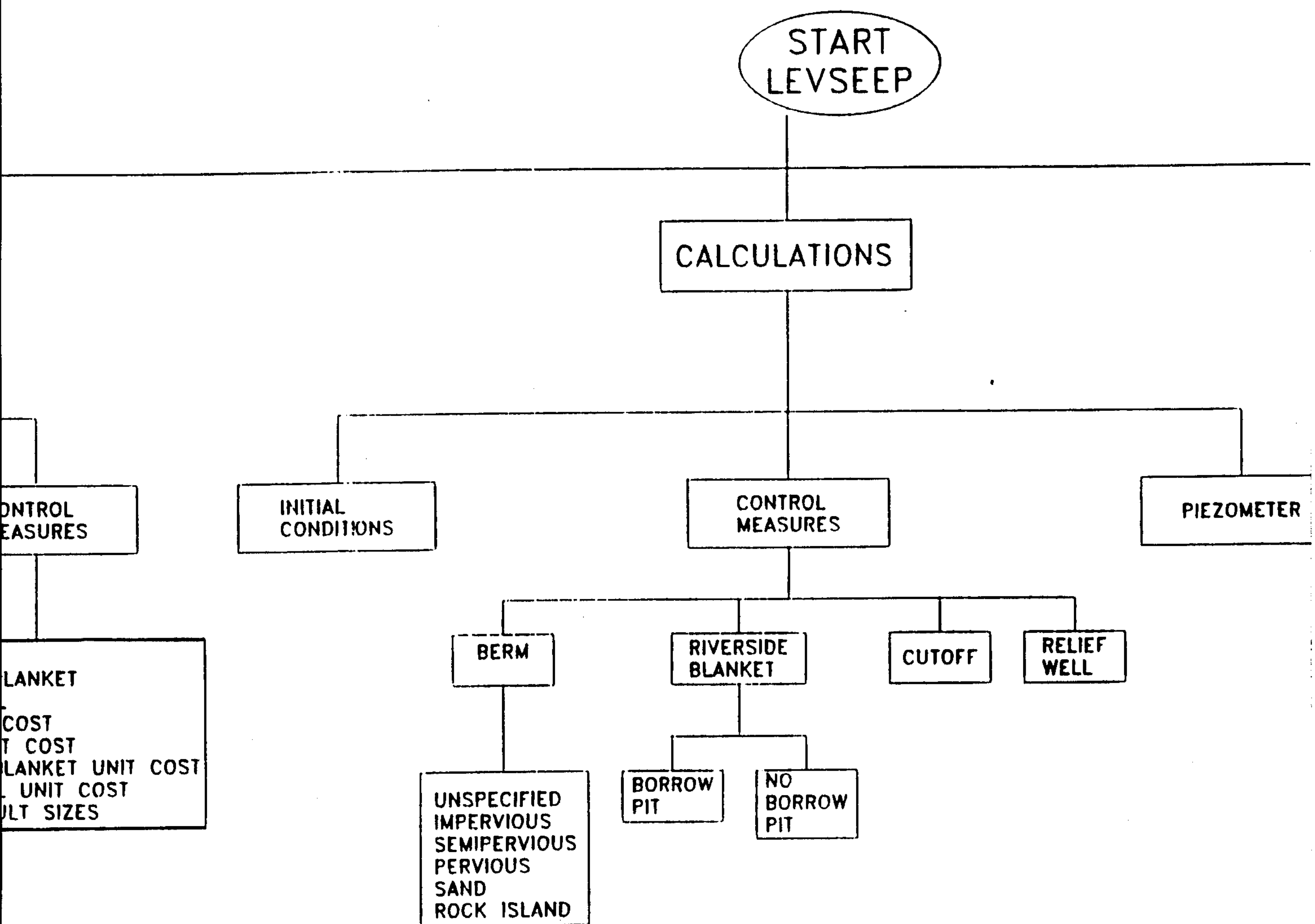
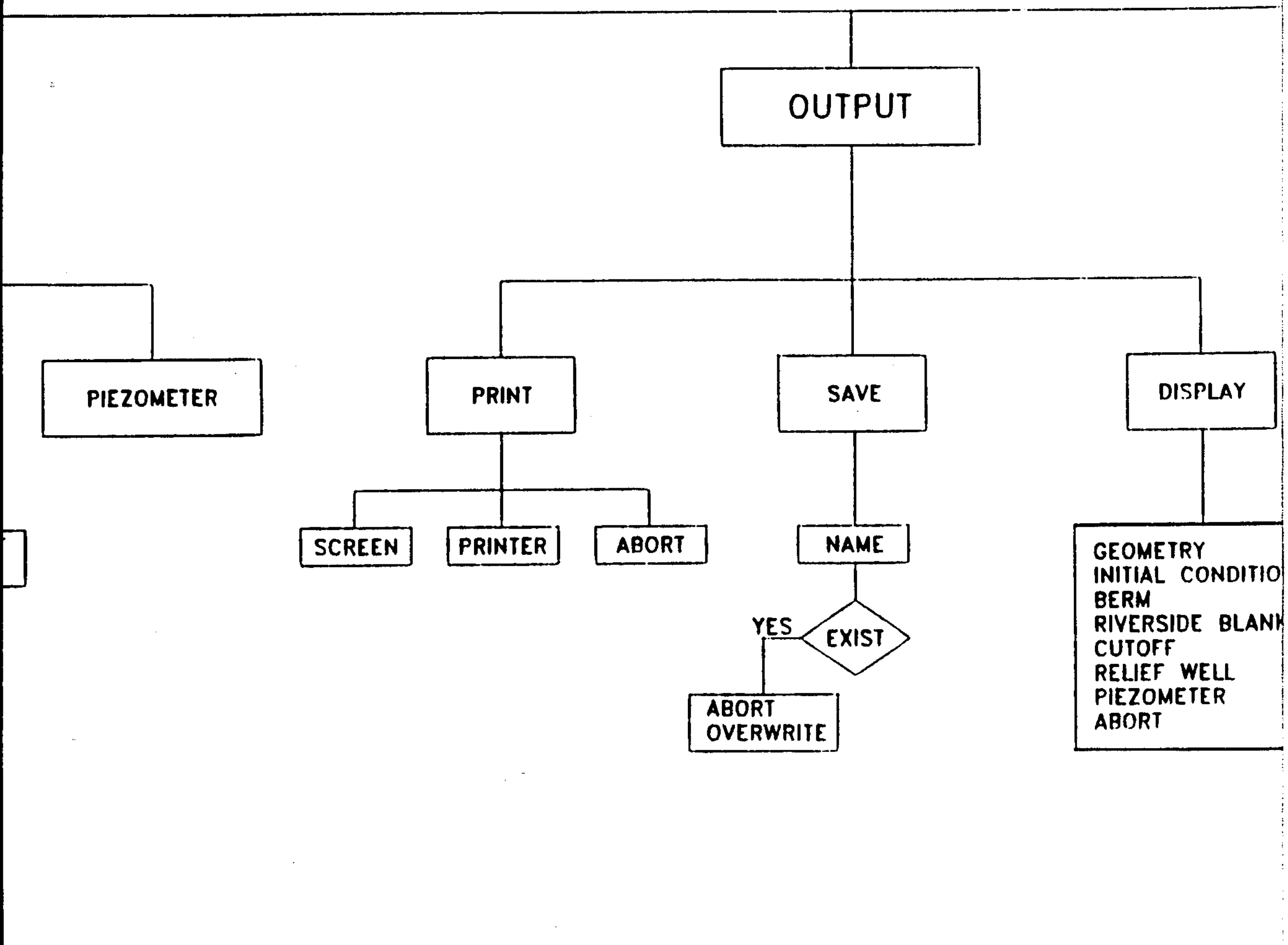

KEYBOARD
CTION
GEOTECHNICAL PROPERTIES
PIEZOMETRIC PROPERTIES
CONTROL MEASURES
INITIAL CONDIT
LAYERS
SUBSTRATUM
LANDSIDE
RIVERSIDE
SINGLE
MULTIPLE
LOCATIONS
READINGS
BERM
RIVERSIDE BLANKET
RELIEF WELL
BERM UNIT COST
CUTOFF UNIT COST
RIVERSIDE BLANKET UNIT COST
RELIEF WELL UNIT COST
BERM DEFAULT SIZES

3

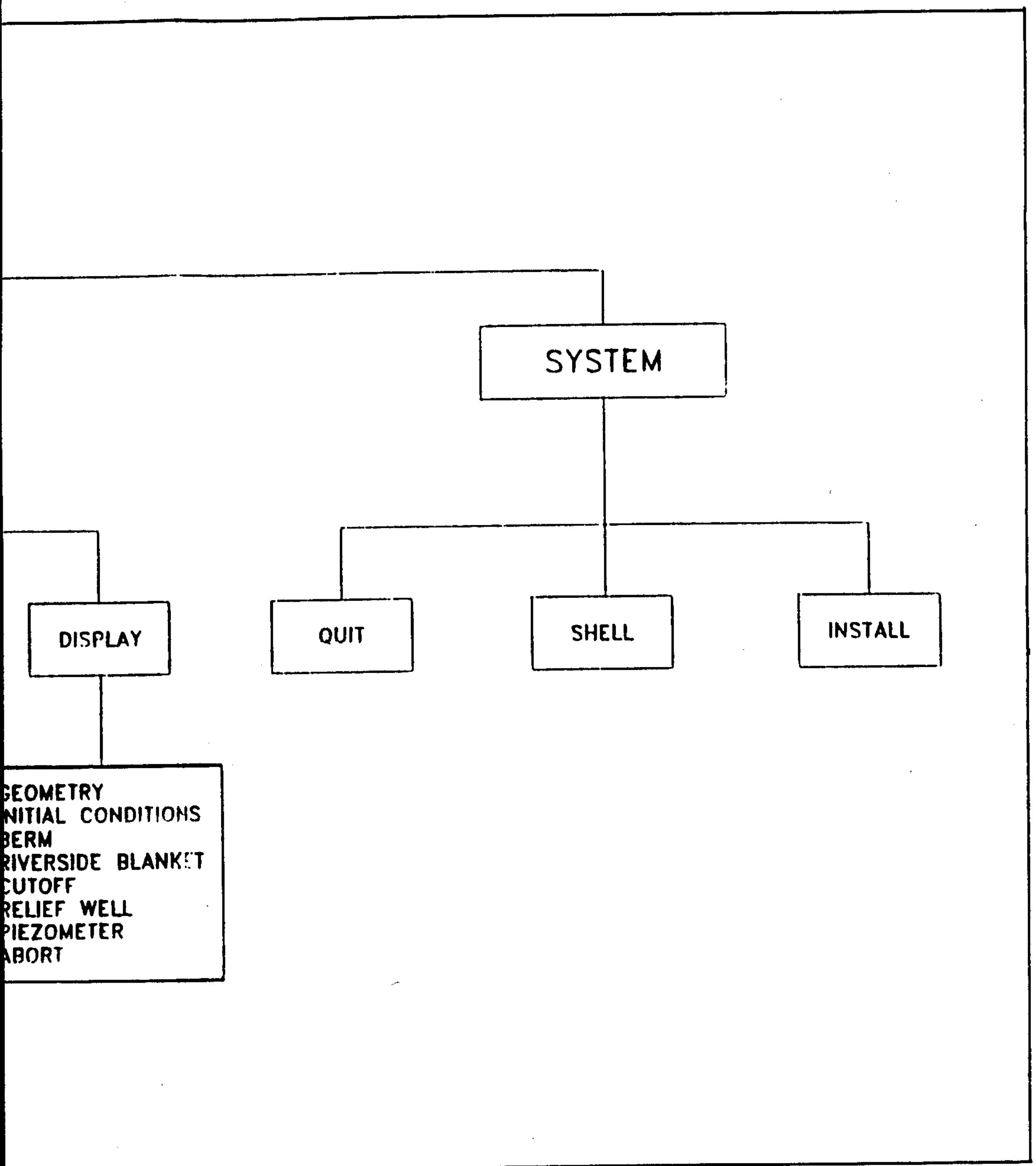

START LEVSEEP
CALCULATIONS
ONTROL EASURES
LANKET
COST
T COST
LANKET UNIT COST
UNIT COST
LT SIZES
INITIAL CONDITIONS
CONTROL MEASURES
PIEZOMETER
BERM
RIVERSIDE BLANKET
CUTOFF
RELIEF WELL
UNSPECIFIED
IMPERVIOUS
SEMIPERVIOUS
PERVIOUS
SAND
ROCK ISLAND
BORROW PIT
NO BORROW PIT

4



OUTPUT
PIEZOMETER
PRINT
SAVE
DISPLAY
SCREEN
PRINTER
ABORT
NAME
YES
EXIST
ABORT
OVERWRITE
GEOMETRY
INITIAL CONDITIO
BERM
RIVERSIDE BLANK
CUTOFF
RELIEF WELL
PIEZOMETER
ABORT

5



SYSTEM
DISPLAY
QUIT
SHELL
INSTALL
EOMETRY
NITIAL CONDITIONS
ERM
IVERSIDE BLANKET
UTOFF
ELIEF WELL
IEZOMETER
BORT

c. *Case No. 3.* Impervious riverside top stratum and no landside top stratum.

d. *Case No. 4.* Impervious landside top stratum and no riverside top stratum.

e. *Case No. 5.* Semipervious riverside top stratum and no landside top stratum.

f. *Case No. 6.* Semipervious landside top stratum and no riverside top stratum.

g. *Case No. 7.* Semipervious top stratum, both riverside and landside.

h. *Case No. 8.* Impervious riverside top stratum (seepage entrance open) and semipervious landside top stratum.

i. *Case No. 9.* Semipervious riverside top stratum and impervious landside top stratum.

A thorough discussion of these cases can be found in Technical Report REMR-GT-13 (Cunny, Agostinelli, and Taylor 1989) and EM 1110-2-1913. The various combinations of geometry and equations for computation of underseepage and substratum pressures can be viewed in Figures 2 and 3.

Control Measures

Berms

Landside berms are analyzed in accordance with EM 1110-2-1913. Nine major cases are considered when calculating for a berm design. The nine major cases considered in berm design are as follows:

a. *Case No. 1.* No top stratum, either landside or riverside.

b. *Case No. 2.* Impervious top stratum, both landside and riverside.

c. *Case No. 3.* Impervious riverside top stratum and no landside top stratum.

d. *Case No. 4.* Impervious landside top stratum and no riverside top stratum.

e. *Case No. 5.* Semipervious riverside top stratum and no landside top stratum.

f. *Case No. 6.* Semipervious landside top stratum and no riverside top stratum.

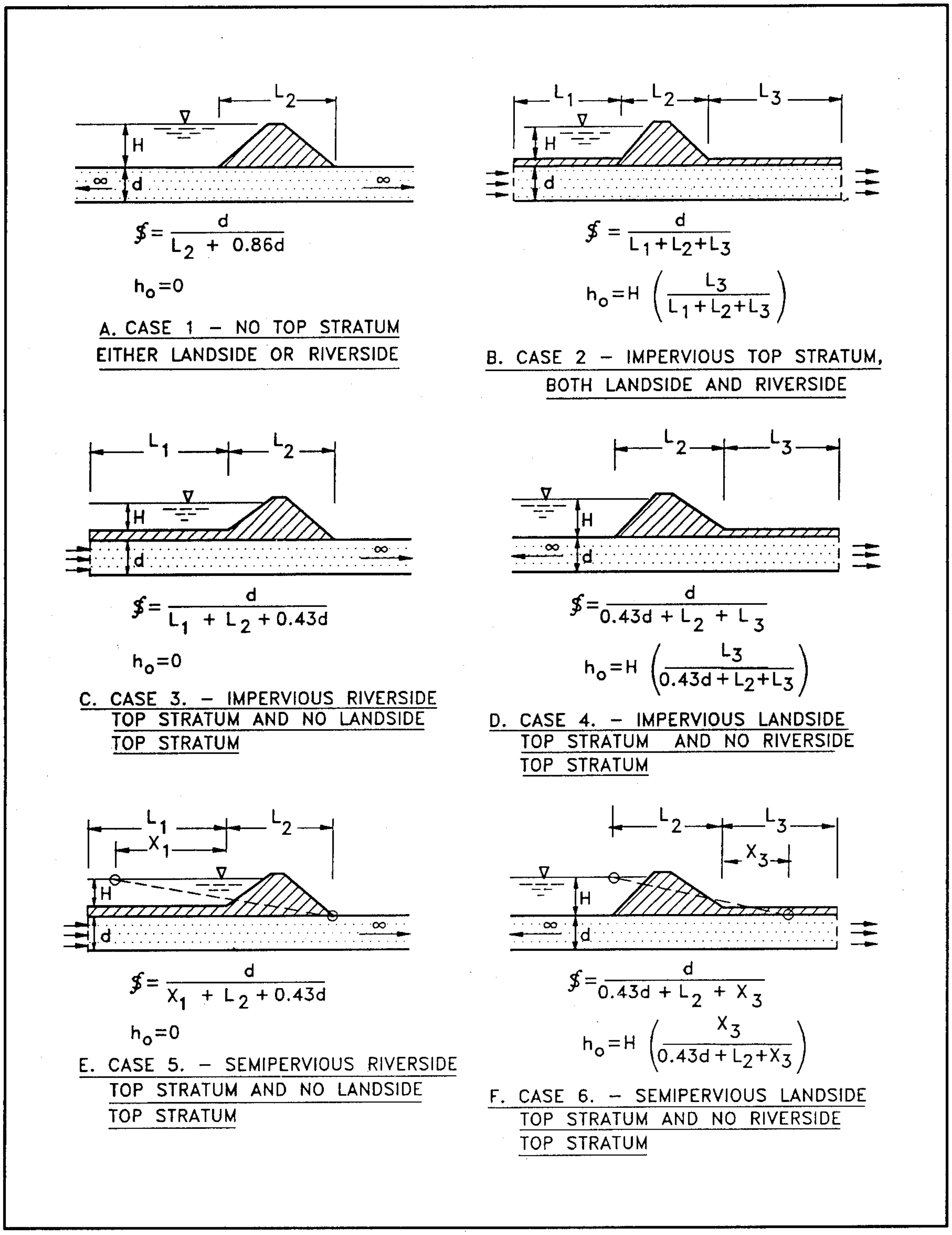


Figure 2. Underseepage combinations: Cases 1 through 6

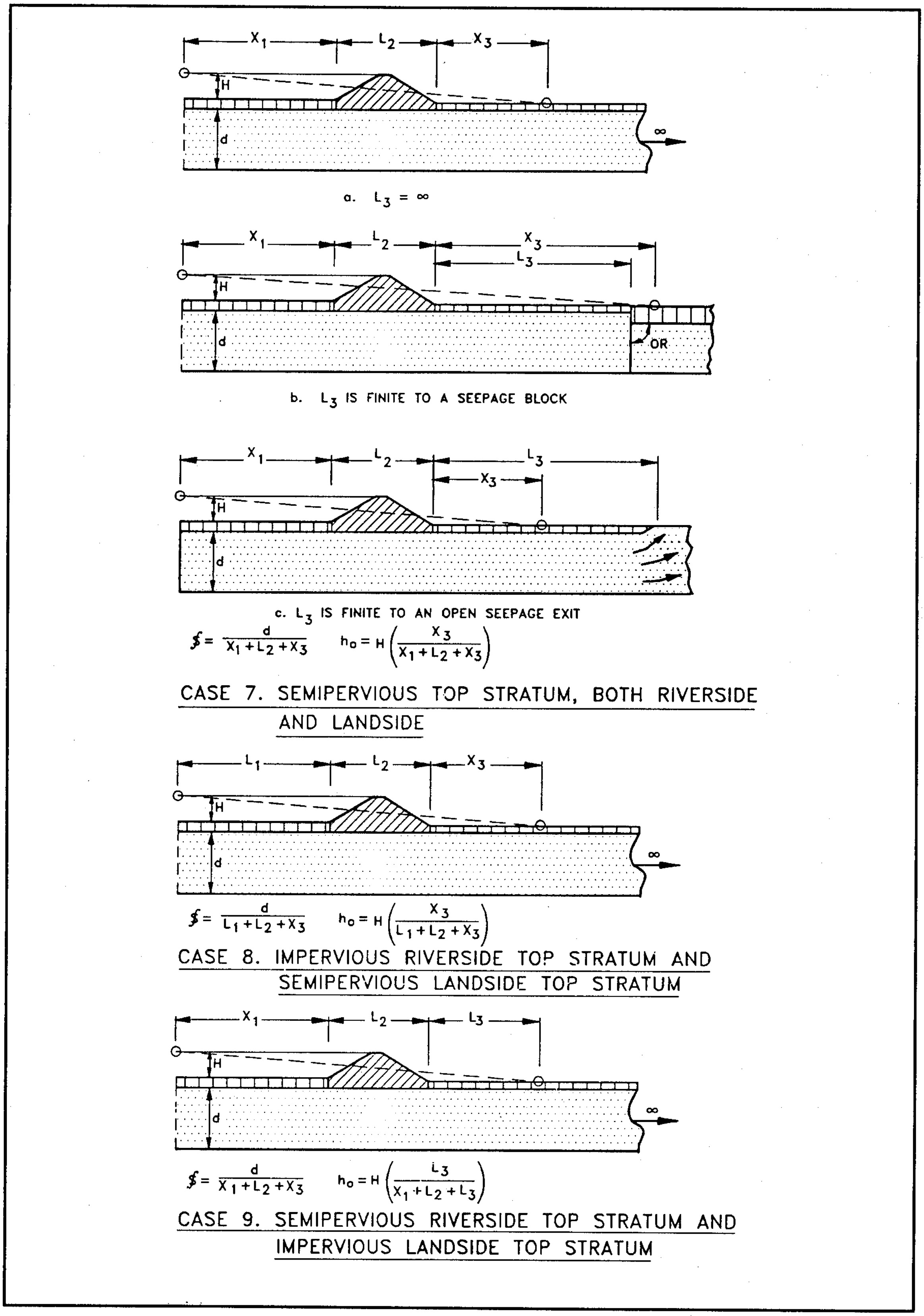


Figure 3. Underseepage combinations: Cases 7, 8, and 9

g. *Case No. 7.* Semipervious top stratum, both riverside and landside.

h. *Case No. 8.* Impervious riverside top stratum and semipervious landside top stratum.

i. *Case No. 9.* Semipervious riverside top stratum and impervious landside top stratum.

In addition, the user may specify the type of berm to be analyzed for Cases 6, 7, and 8. Those choices of berm types consist of impervious, semipervious, pervious with a collector pipe, sand, and Rock Island District berm. A typical levee section with a landside berm can be seen in Figure 4.

Riverside blankets

Riverside blankets are analyzed using the equations of U.S. Army Engineer Waterways Experiment Station (1956). Four major cases of blankets are analyzed in LEVSEEP. Those cases consist of the following:

a. *Case No. 1.* No natural riverside top stratum.

(1) Blanket of uniform thickness.

(2) Triangular blanket.

b. *Case No. 2.* Existing natural top stratum and blanket from levee to river.

c. *Case No. 3.* Natural top stratum riverward of borrow pit assumed infinite ($L_1 > 2{,}000$ ft) and to have same characteristics as top stratum and uniform blanket in borrow pit.

d. *Case No. 4.* Natural top stratum riverward of borrow pit assumed infinite ($L_1 > 2{,}000$ ft) and impervious ($k < 0.05 \times 10^{-4}$ cm/sec) with a uniform blanket in borrow pit.

It should be noted that for Case 1 the user may choose to perform an analysis for a blanket of uniform thickness or a triangular blanket. The four cases of blanket conditions are illustrated in Figures 5 and 6.

Cutoffs

The design of cutoffs to control seepage is calculated using the methods of fragments (Harr 1962). As many as five fragments are used, as shown in Figure 7. The form factors for these fragments are as follows:

$$\Phi_1 = \phi_5 = 0.43 \tag{1}$$

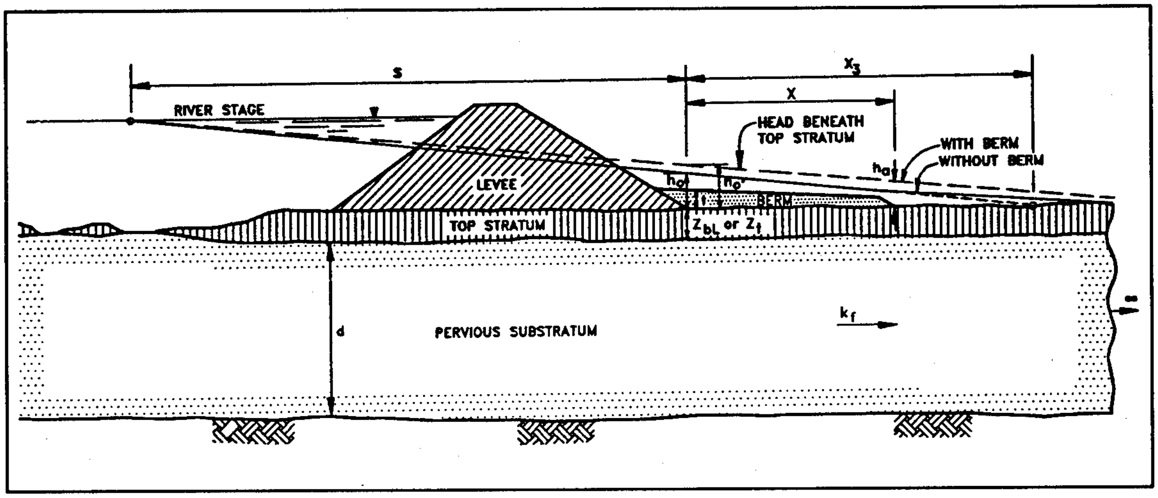


Figure 4. Typical berm section

$$\phi_2 = \frac{x_1}{d} \tag{2}$$

$$if\ L_2 \geq d_c\ ,\ \phi_3 = \ln\left[1 + \frac{d_c}{d - d_c}\right] + \frac{L_2 - d_c}{d}$$

$$= \ln\left[\frac{1}{\frac{1 - d_c}{d}}\right] + \frac{x_3}{d} - \frac{d_c}{d} \tag{3}$$

$$if\ L_2 < d_c\ ,\quad \phi_3 = \ln\left[\frac{1}{\frac{1 - d_c}{d}}\right] \tag{4}$$

$$if\ x_3 \geq d_c\ ,\ \phi_4 = \ln\left[1 + \frac{d_c}{d - d_c}\right] + \frac{x_2 - d_c}{d}$$

$$= \ln\left[\frac{1}{\frac{1 - d_c}{d}}\right] + \frac{x_3}{d} - \frac{d_c}{d} \tag{5}$$

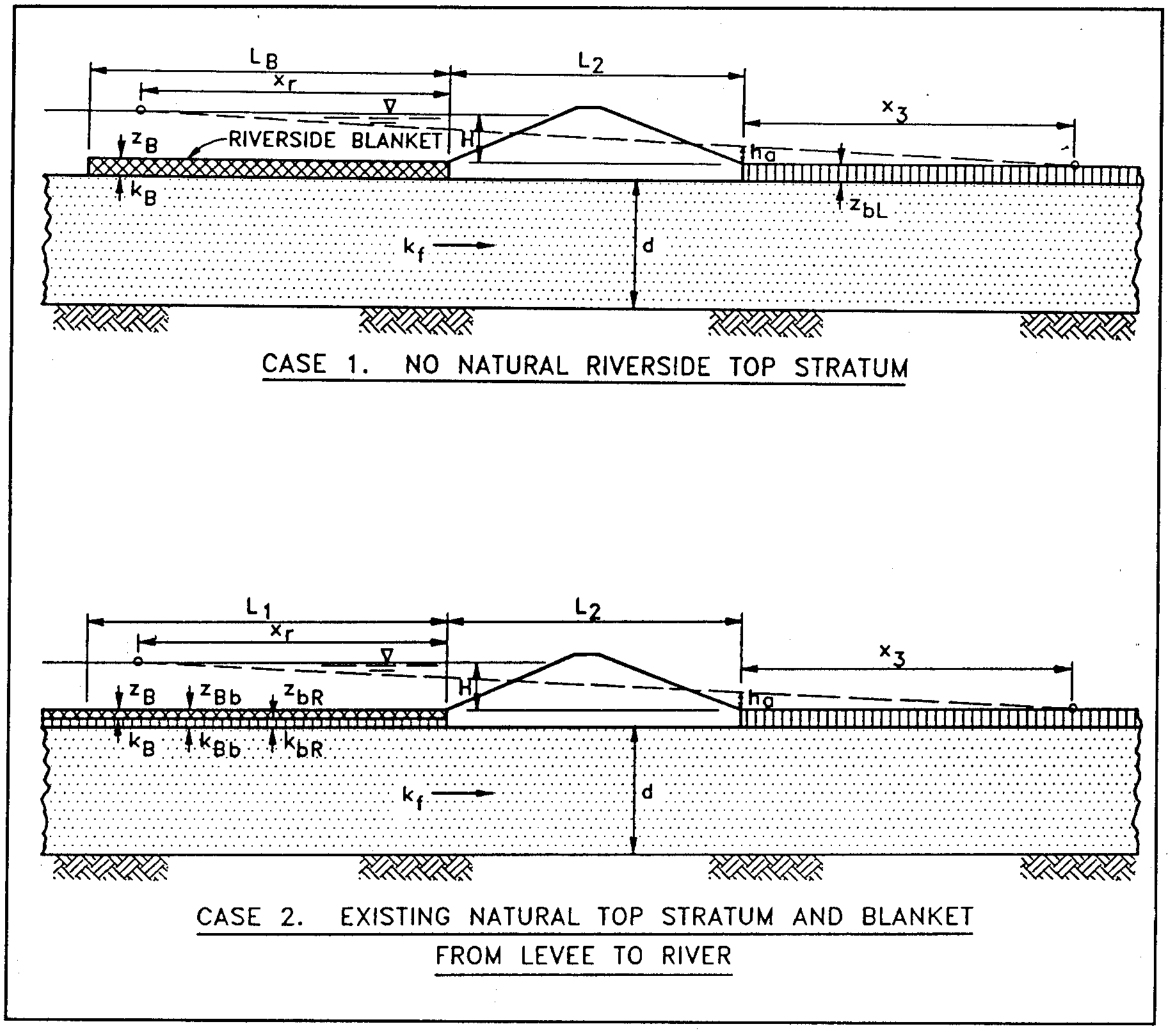


Figure 5. Riverside blanket conditions: Cases 1 and 2

$$\textit{if } x_3 < d_c\,, \quad \phi_4 = \ln\left[\frac{\dfrac{1}{1-d_c}}{d}\right] \tag{6}$$

$$\textit{For } x_3 = 0, \quad \phi_4 = \frac{k}{k'} \quad \textit{with modulus} \quad m = \sin\frac{\pi d_c}{2d} \tag{7}$$

Note: *Use* ϕ_1 *only when* $x_1 = 0$.

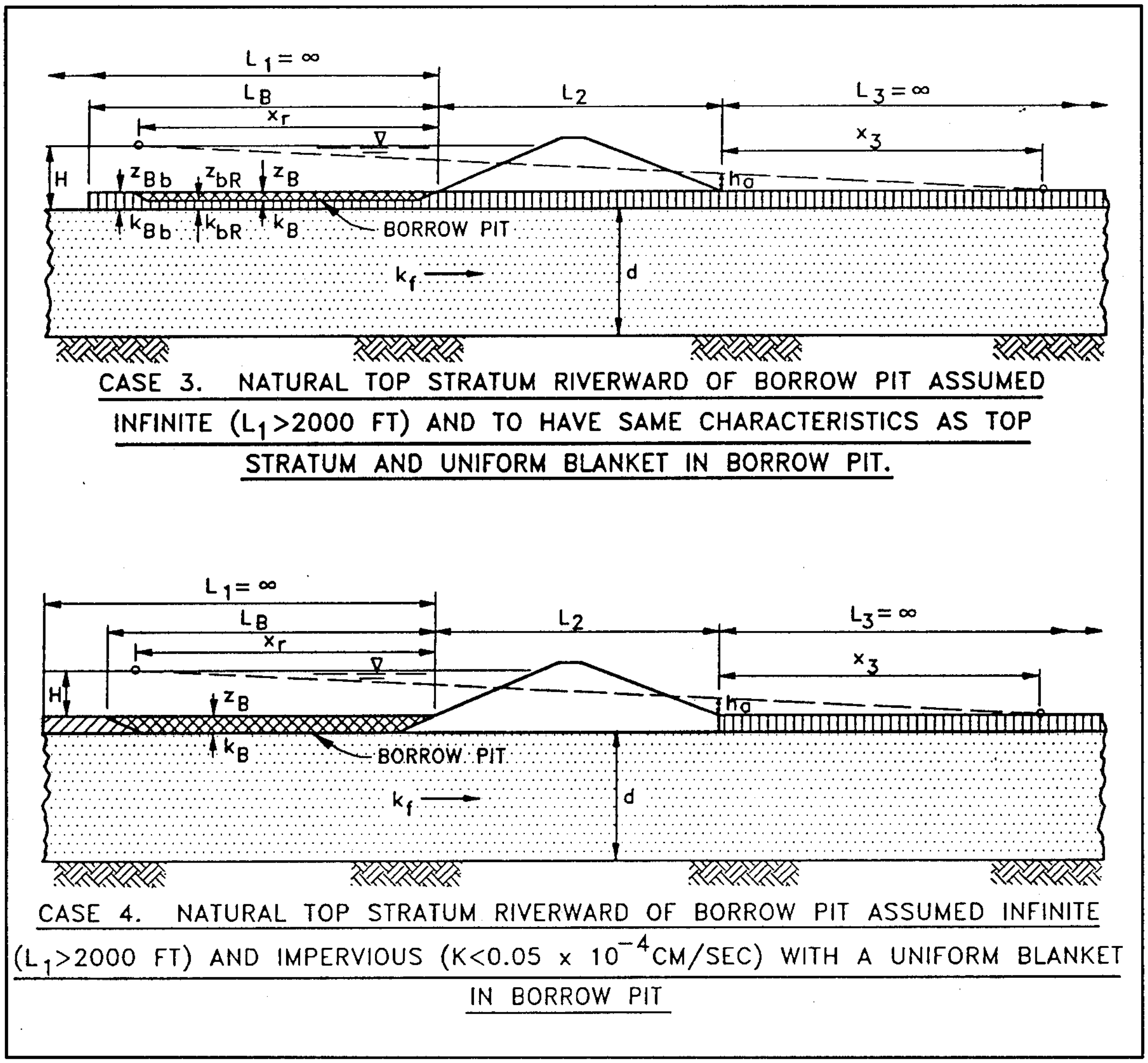


Figure 6. Riverside blanket conditions: Cases 3 and 4

Note: *Use* ϕ_5 *only when* $x_3 = 0$ *and* $d_c = 0$

Observe that the analysis of cutoffs by the method of fragments occasionally produces a technically troublesome result. Specifically, in some cases an increase in cutoff depth fails to produce a decrease in the upward gradient at the landside toe. After some investigation, it was determined that this problem stems from the low ratio of cutoff depth to levee width in Fragment 3 of Figure 7. Such a ratio is significantly less than that, for this type of fragment was intended when used to analyze the weir structures for which it was developed. Harr (1962) described a similar situation. A thorough discussion of this topic can be found in Technical Report REMR-GT-13 (Cunny, Agostinelli and Taylor 1989). A technically

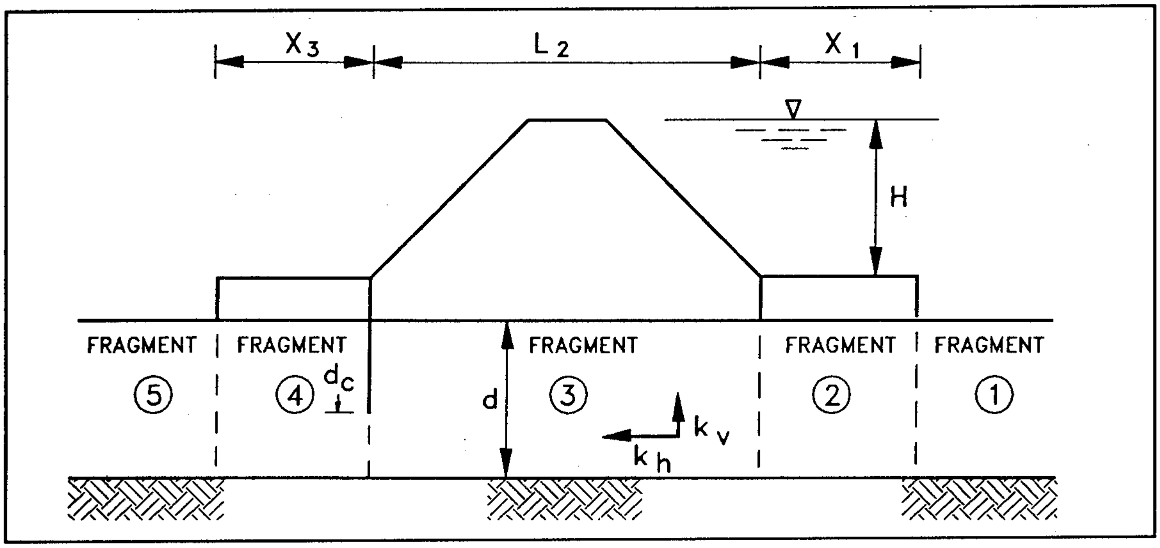


Figure 7. Schematic for analysis of cutoff by method of fragments

acceptable analysis of cutoffs is possible through use of the finite element method (Bathe 1982) but only at a greater computational cost.

Relief wells

For these calculations, an allowable head at the landside toe of the levee is determined based on the critical gradient at that location and a user-selected factor of safety. The program then determines those combinations of well spacing and penetration which satisfy the criterion that the head midway between wells is equal to the allowable head at the landside toe of the levee. The well penetrations examined in the program range from 25 to 100 percent in increments of 12.5 percent, and well spacings range from 25 to 300 ft. Figure 8 shows a typical levee section with a line of relief wells.

Head losses in a well consist of screen and filter entrance losses, friction losses in the screen and riser pipe, velocity losses, and elevation losses. Screen and filter entrance losses are estimated from pumping tests on a 16-in.-diam wood stave well screen with a 6-in. sand filter, as presented in Figure 9. This figure may give somewhat high values of loss for steel and plastic well screens in current use. However, entrance loss data were not available for those materials, and the use of Figure 9 should result in conservative values.

Friction losses in the well screen and riser pipe are calculated according to the Darcy-Weisbach formula as described in EM 1110-2-1602. The resistance coefficient in the formula is solved by the Colebrook-White equation, also taken from EM 1110-2-1602. The computer code for the solution of the Colebrook-White equation was obtained from U.S. Army Engineer Waterways Experiment Station (1973). That equation requires the input of an effective

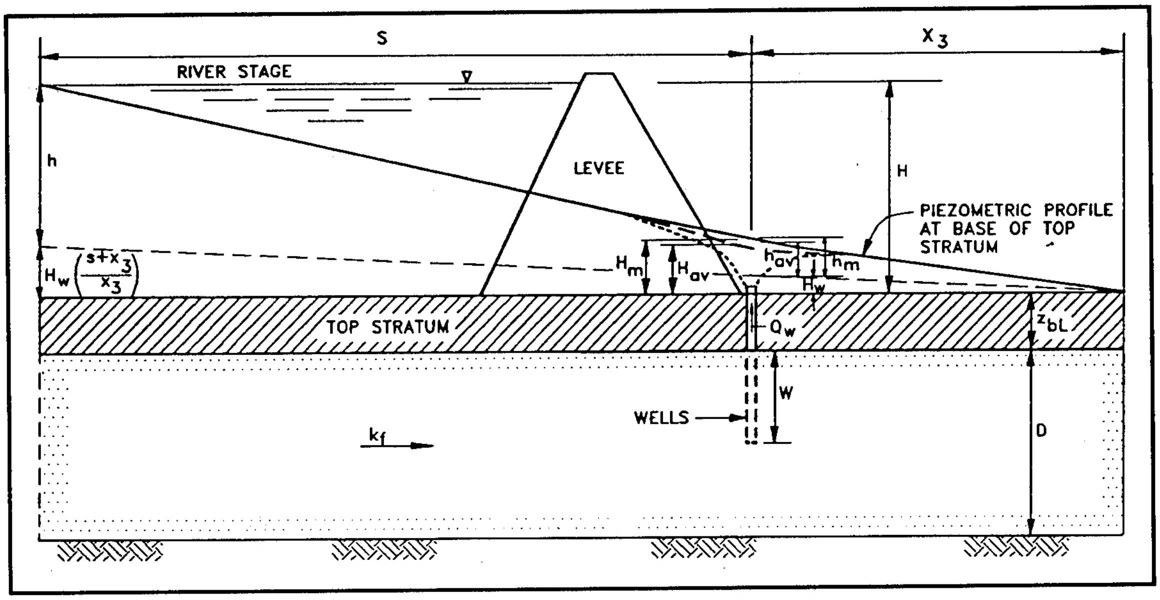


Figure 8. Typical relief well section

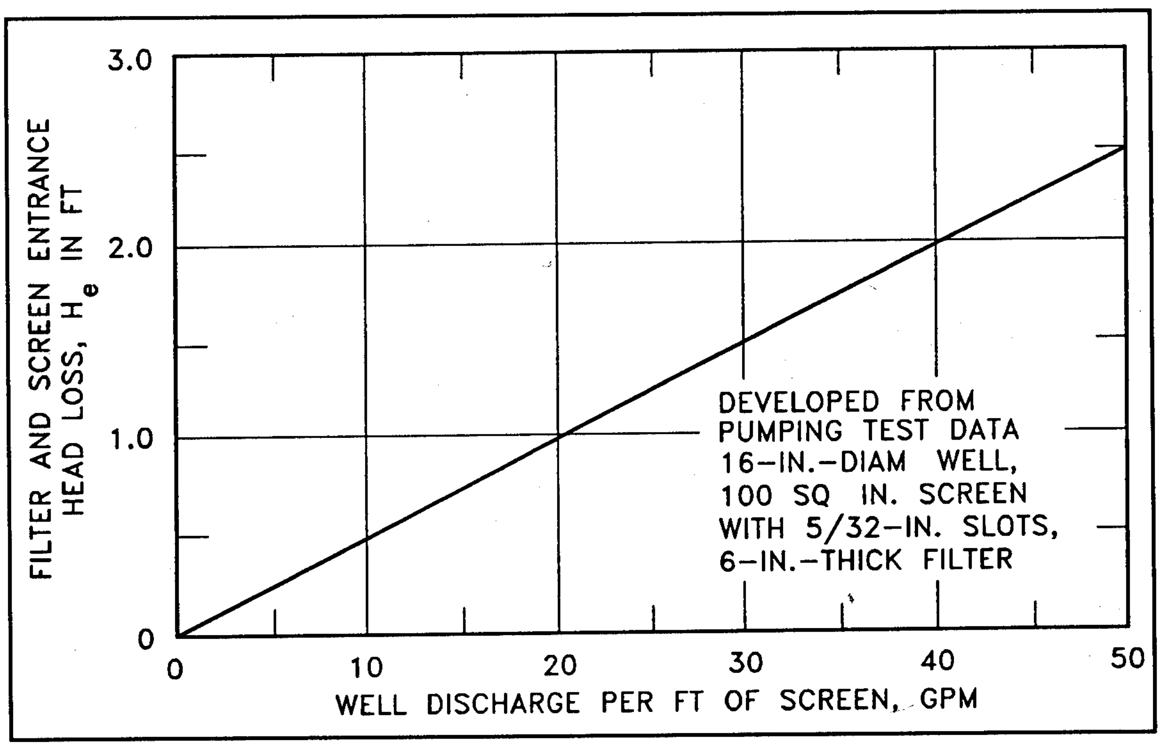


Figure 9. Screen and filter entrance losses (U.S. Army Engineer Division, Huntsville 1986)

roughness parameter for the material comprising the well screen and riser pipe. The program has default values of the roughness parameter for stainless steel, galvanized steel, and plastic pipe estimated from information given in EM 1110-2-1602. The user may enter other values if desired. In accordance with recommendations in Engineer Bulletin 55-11 and U.S. Army Engineer District, Huntsville (1986), one-half the screen length is used to compute friction losses in the well screen.

Velocity head losses are computed as velocity squared divided by two times the acceleration of gravity. Elevation head is taken as the height of well top above tailwater. No provision is made to estimate head losses from fountain flow out of the well top.

Calculations for the average head in the line of wells and the head midway between wells are accomplished using the formulas in TM 3-424 and Engineer Bulletin 55-11. These formulas require inputs of uplift factors which are scaled from a nomograph shown in both references. This nomograph is presented as Figure 10 in this report. A computer solution to the nomograph was obtained from Conroy (1984) and is incorporated in the program. Conroy (1984) has indicated that the computer solution may diverge somewhat from values of uplift factors estimated from the nomograph for values of D/a less than 0.3 and greater than 4.0, where D is the effective thickness of the pervious foundation and a is the well spacing, but this solution was not significant for practical well spacings. TM 3-424 requires the use of the simple chart shown in Figure 11 for the determination of head losses; however, LEVSEEP utilizes the technically more accurate equations described previously. For this reason, the computer solution is slightly different than the solution obtained by hand calculations in some cases and is technically superior. Technical Report REMR-GT-13 (Cunny, Agostinelli, and Taylor 1989) provides a thorough discussion of this divergence.

For the special case of no landside top stratum, the aforementioned procedure for well analysis is not valid since there is a no landside blanket through which to calculate an allowable head. However, it is sometimes desired to channel a portion of the levee underseepage into a well system in order to reduce uncontrolled flow and to minimize the possibility of development of piping or sand boils (U.S. Army Engineer Waterways Experiment Station 1956). The program provides for the analysis of a well system in this special case of no landside top stratum. The user selects the percentage reduction in levee underseepage which will be intercepted by the well system. The program then calculates the required spacings of wells for different depths of penetration, such that the well discharge per 100 ft of levee equals the desired reduction in underseepage flow.

For each selected combination of well spacing and penetration that satisfies the design criteria, the cost of the well system per 100 ft of levee is calculated; the program identifies the least cost combination of penetration and well spacing. Elements included are the cost of drilling through the top stratum and pervious foundation and cost of well screen, riser pipe and filter;

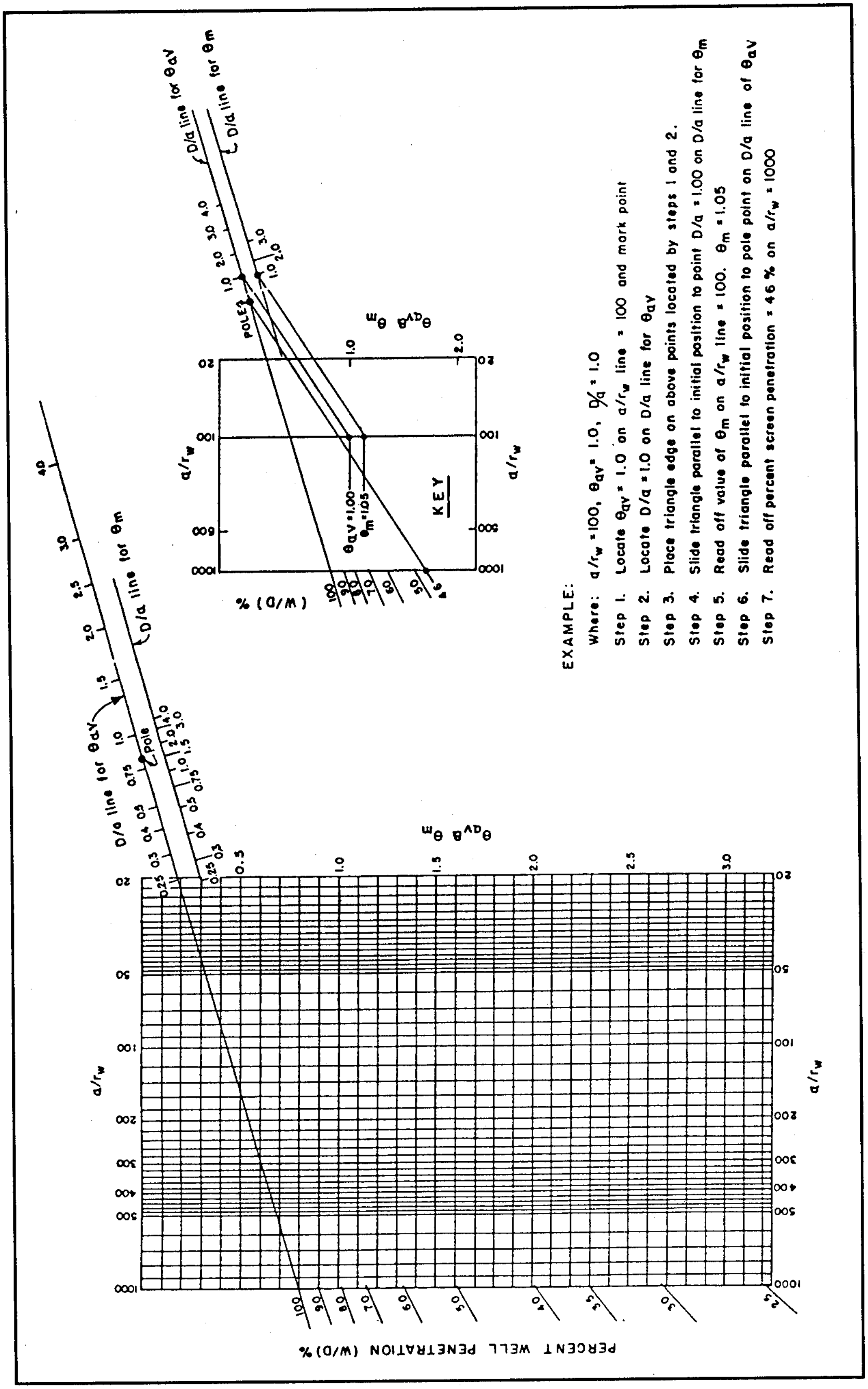


Figure 10. Nomographic chart for design of relief well systems (U.S. Army Engineer Waterways Experiment Station 1956)

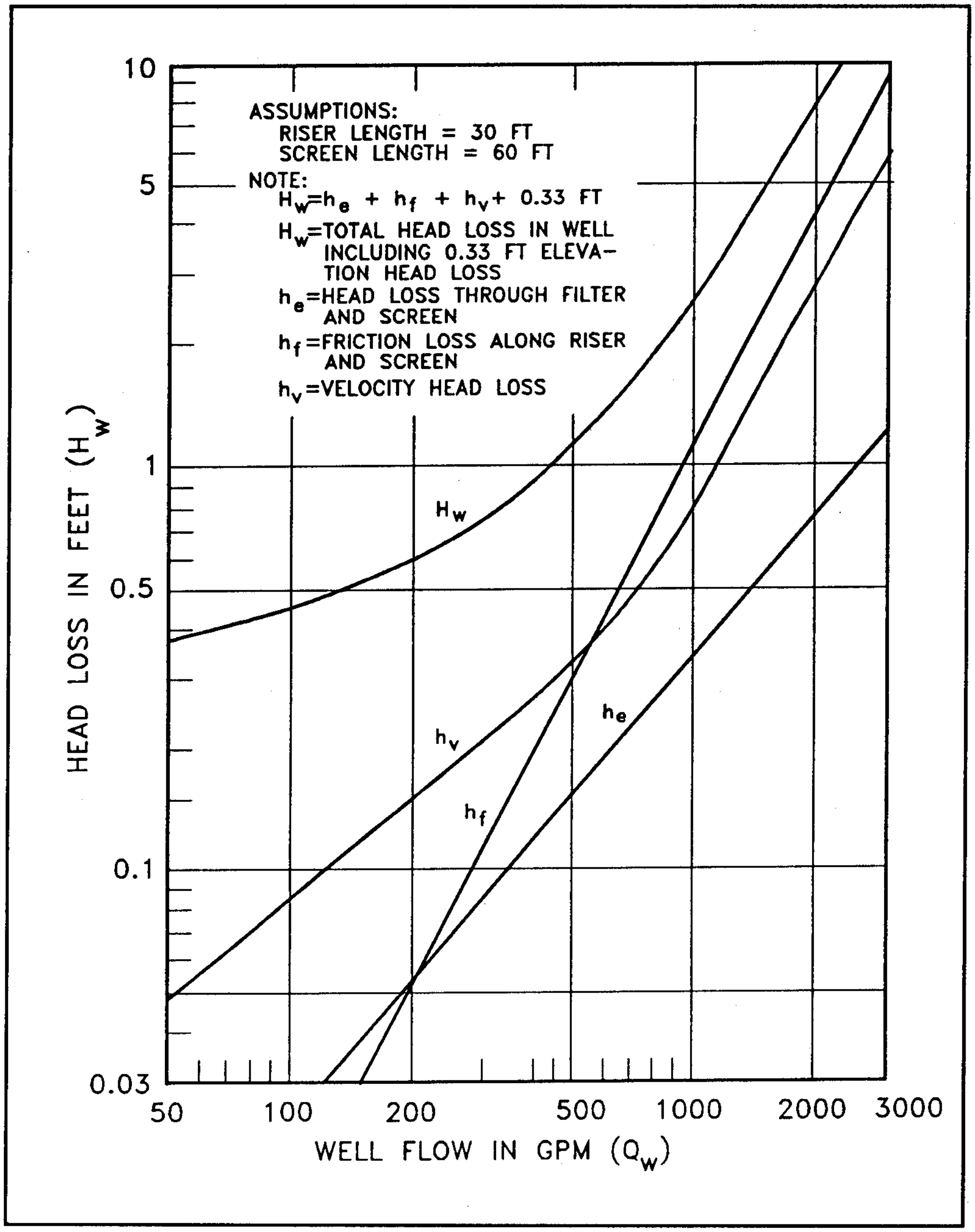


Figure 11. Hydraulic head losses in 8-in.-one-dimensional woodstave well with 6-in. gravel filter (U.S. Army Engineer Waterways Experiment Station 1956)

these items are priced by the linear foot. Lump sum costs include backfilling, well cover, and well development and testing. Options are provided for the user to select well screens and riser pipes of stainless steel, galvanized steel, or plastic.

Input

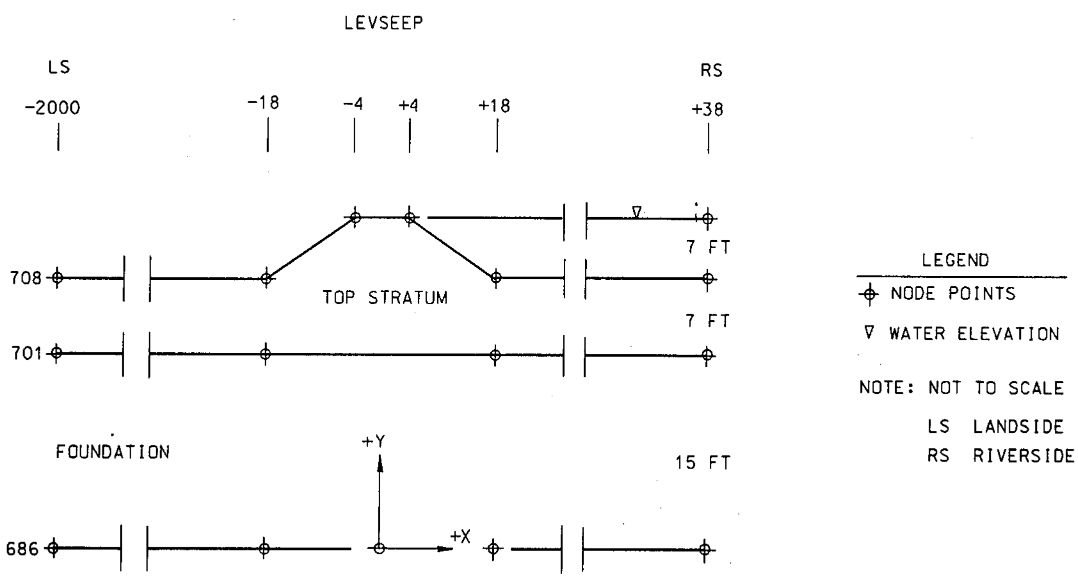
LEVSEEP accepts input either from keyboard entry or from an existing ASCII file. Figure 12 shows an example input data file for LEVSEEP. While LEVSEEP can read from a file, it is typically easier to enter data through the input/edit screens. This file provides the user with prompts for units and other useful information. Once a file exists, the user can load files and modify them quite easily. Input data for the program include cross-section data, geotechnical properties, piezometer data, and control measure information. A thorough discussion of each of these data sets is included in Chapter 3.

Output

LEVSEEP will provide the user with a complete summary of all calculations performed on a levee section. This summary includes initial conditions; output data from berm analysis, riverside blanket analysis, cutoff analysis, and relief well analysis; and a cost summary for all the control measures analyzed. The summary may be saved to file, printed to the screen, or sent to a printer. Figure 13 provides a sample summary output. The results of each analysis may be viewed graphically through the Display option. The graphic display may be sent to a file, the screen, or a Hewlett-Packard plotter. A complete set of display option output screens can be found in Appendix A of this report.

System

Accessing the system option allows the user to quit the program, shell to DOS, or change the installation default settings for LEVSEEP. The default configuration for LEVSEEP is shown in Figure 14.




```
"CROSS SECTION"
26,"/ numline"
1,-1600,164.5,"/ line.num(), sect.x(), sect.y()"
1,-400,164.5,"/ line.num(), sect.x(), sect.y()"
1,-390,168,"/ line.num(), sect.x(), sect.y()"
1,-125,178,"/ line.num(), sect.x(), sect.y()"
1,-10,201.3,"/ line.num(), sect.x(), sect.y()"
1,10,201.3,"/ line.num(), sect.x(), sect.y()"
1,110,170,"/ line.num(), sect.x(), sect.y()"
1,190,167.5,"/ line.num(), sect.x(), sect.y()"
1,200,164.5,"/ line.num(), sect.x(), sect.y()"
1,400,164.5,"/ line.num(), sect.x(), sect.y()"
1,401,155,"/ line.num(), sect.x(), sect.y()"
1,1200,157,"/ line.num(), sect.x(), sect.y()"
1,1201,164.5,"/ line.num(), sect.x(), sect.y()"
1,1600,164.5,"/ line.num(), sect.x(), sect.y()"
2,-800,153,"/ line.num(), sect.x(), sect.y()"
2,200,153,"/ line.num(), sect.x(), sect.y()"
2,201,151,"/ line.num(), sect.x(), sect.y()"
2,400,151,"/ line.num(), sect.x(), sect.y()"
2,401,157,"/ line.num(), sect.x(), sect.y()"
3,1200,157,"/ line.num(), sect.x(), sect.y()"
3,1201,151,"/ line.num(), sect.x(), sect.y()"
3,1600,151,"/ line.num(), sect.x(), sect.y()"
4,-800,164.5,"/ line.num(), sect.x(), sect.y()"
4,-800,113,"/ line.num(), sect.x(), sect.y()"
5,-1600,113,"/ line.num(), sect.x(), sect.y()"
5,1600,113,"/ line.num(), sect.x(), sect.y()"
""
"GEOTECHNICAL PROPERTIES"
"EXAMPLE PROBLEM - X-SECTION 5.","CROSS-5",164.5,400,200,29.8,"200","400","open"
,"blocked",50,1,1,1,"/ pjnm$, geo.station$, lte, lto, rto, h, L1$, L3$, ENTRANCE
$, EXITt$, subwt, substrat, lndstrat, rivstrat"
.25,40,40,11.5,.00015,13.5,.00002,11.5,14,1.142081E-03,3.849002E-04,"/ KF, DD, D
, ZBL, kbl, zbr, kbr, zt, ZL, CBL, cbr"
40,.25,0,"/ dn(), khn(), kvn()"
0,0,0,"/ lndtype(), lndthick(), lkb()"
0,0,0,"/ rivtype(), rivthick(), rkb()"
""
```

Figure 12. Sample input file (Continued)

```
"PIEZOMETER PROPERTIES"
5,"/ pznum"
"b-3","38+00 ","20u/s ",140,200,"/ pzl.number$(), pz.station$(), pz.offset$(), t
ip.elev(), top.elev()"
"b-4","38+00","200d/s",145,175,"/ pzl.number$(), pz.station$(), pz.offset$(), ti
p.elev(), top.elev()"
"b-5","38+00","400d/s",140,165,"/ pzl.number$(), pz.station$(), pz.offset$(), ti
p.elev(), top.elev()"
"b-6","38+00","600d/s",135,165,"/ pzl.number$(), pz.station$(), pz.offset$(), ti
p.elev(), top.elev()"
"b-7","38+00","985d/s",130,165,"/ pzl.number$(), pz.station$(), pz.offset$(), ti
p.elev(), top.elev()"
"PIEZOMETER READINGS"
5,"/ pznum"
"b-3","05/09/1973",175.3,178.2,"/ pzr.number$(), date.read$(), pz.read(), pool.r
ead()"
"b-4","05/09/1973",174.1,178.2,"/ pzr.number$(), date.read$(), pz.read(), pool.r
ead()"
"b-5","05/09/1973",172.4,178.2,"/ pzr.number$(), date.read$(), pz.read(), pool.r
ead()"
"b-6","05/09/1973",167.3,178.2,"/ pzr.number$(), date.read$(), pz.read(), pool.r
ead()"
"b-7","05/09/1973",172.5,178.2,"/ pzr.number$(), date.read$(), pz.read(), pool.r
ead()"
"05/09/1973"

""
"BERM CONTROL MEASURES"
0,.3,.8,.076,.25,"/ fsb,IOB,il,ml,m3b"
""
"RIVER BLANKET CONTROL MEASURES"
.7,.25,.19,"/ IA, m3r,m4"
""
"RELIEF WELL CONTROL MEASURES"
0,.53,1,.67,.0001,.0000121,1,.33,0,"/ fsw, iOw, RW, dp, ruff, viscos, j, hel, PE
RSEEP"
""
"BERM UNIT COST"
1.3,1.3,1.3,3.75,3.75,3.75,"/ unspbm, impvbm, semibm, sandbm, pervbm, rckisbm"
""
"RIVERSIDE BLANKET UNIT COST"
1.2,"/ blkcost"
""
"CUTOFF UNIT COST"
2,"/ levnum"
65,3,"/ cutoff.depth(), cutoff.cost()"
-1,8,"/ cutoff.depth(), cutoff.cost()"
""
"RELIEF WELL UNIT COST"
20,16,30,85,12,400,300,1000,"/ drt, drp, rp, ws, fl, bf, wc, wd"
```

Figure 12. (Concluded)

```
PROJECT NAME : STOVALL, MISSISSIPPI
STATION      : 77/38+00

                  INITIAL CONDITIONS
                  ------------------

X1 =   199.61 FT
X3 =  2048.18 FT
M  =  0.0105
I  =  1.8637
Qs =  154.20 GPM/100 FT

HO    =    21.43 FT
$     =  0.0140

             OUTPUT DATA FOR BERM ANALYSIS
             ----------------------------

IMPERVIOUS BERM

 X1 =   199.61 FT
 X3 = UNDEFINED
 M  = UNDEFINED
 I  = UNDEFINED
 Qs = UNDEFINED

 X  =   400.00 FT
 T  =    12.13 FT

SEMIPERVIOUS BERM

 X1 =   199.61 FT
 X3 = UNDEFINED
 M  = UNDEFINED
 I  = UNDEFINED
 Qs = UNDEFINED

 X  =   400.00 FT
 T  =    12.13 FT

          OUTPUT DATA FOR BLANKET ANALYSIS
          -------------------------------

X1 =  4718.33 FT
X3 =  2048.18 FT
M  =  0.0039
I  =  0.7014
Qs =   58.03 GPM/100 FT

XR  =  4733.90 FT
LB  =   800.00 FT
KB  =  0.0000
ZB  =     3.56 FT

          OUTPUT DATA FOR CUTOFF ANALYSIS
          ------------------------------

X1 =   199.61 FT
X3 =  2048.18 FT
M  =  0.0106
I  =  1.7995
Qs =  145.82 GPM/100 FT

DC/D = .95
```

Figure 13. Sample summary output (Continued)

```
          OUTPUT DATA FOR RELIEF WELL ANALYSIS
          ------------------------------------

   X1 =    199.61 FT
   X3 =   2048.18 FT
   M  = UNDEFINED
   I  = UNDEFINED
   Qs =   154.03 GPM/100 FT
   J  =   0  %
```

P ft	ASEL ft	WBAR ft	QW gal/100 ft	COST $
0.25	94.90	10.00	370.26	3719.86
0.38	125.86	15.00	469.62	3253.71
0.50	149.86	20.00	599.83	3109.57
0.63	168.42	25.00	665.85	3102.43
0.75	182.73	30.00	708.29	3168.63
0.88	193.89	35.00	771.33	3277.65
1.00	202.68	40.00	782.30	3414.31
0.63	168.42	25.00	665.85	3102.43

```
            FROM PIEZOMETER DATA
            --------------------

   X1 =    351.67 FT
   X3 =   1560.01 FT
   M  =  0.0055
   I  =  0.7399
   Qs =    80.38 GPM/100 FT
   H  =    13.70 FT
   l1 =   420.00 FT
   h1 =    26.21 FT
   l2 =   800.00 FT
   h2 =     9.60 FT
   H0 =     8.51 FT
   S  =   799.61 FT

      COST SUMMARY FOR ALL CONTROL MEASURES
      -------------------------------------
```

TYPE	VOLUME CU YD/100 FT	UNIT COST $	TOTAL $
IMPERVIOUS BERM	15726.09	1.30	20443.91
SEMIPERVIOUS BERM	15726.09	1.30	20443.91
PERVIOUS BERM	15726.09	3.75	58972.82
SAND BERM	15726.09	3.75	58972.82
RIVERSIDE BLANKET	12671.44	1.20	10559.53

```
CUTOFF
------
DC/D =       .95
DEPTH =        52.00 FT
TOTAL =        15600.00 $

RELIEF WELL - LOWEST COST
-------------------------
DEPTH =         25.00 FT
SPACING =      168.42 FT
TOTAL =          3102.43 $
```

Figure 13. (Concluded)

```
                     INSTALLATION MENU

PORT FOR PLOTTER          com1

PORT FOR PRINTER          lpt1

UNITS                     ft

DEFAULT DIRECTORY



                                      <Esc> exit screen

      COM1, COM2, COM3
```

Figure 14. Default configuration for LEVSEEP

3 Program Execution

LEVSEEP is a stand-alone QuickBASIC program. To begin execution of the program, the user needs only to type LEVSEEP into the computer at the DOS prompt followed by the enter key. While LEVSEEP can operate from a 3.5- or 5.25-in. disk drive, the user may wish to create a subdirectory for LEVSEEP on the hard drive and copy all files to this directory. LEVSEEP also operates faster with the aid of a math coprocessor. However, a math coprocessor is not required for operation.

General guidance for program execution is as follows:

a. LEVSEEP operates from a main menu with the following options:

(1) INPUT/EDIT DATA from File

New

Load file

Save file

Print file

(2) INPUT/EDIT DATA from KEYBOARD

Cross-section or X-section

Geotechnical properties

Piezometric properties

Control measure

(3) CALCULATIONS

Initial conditions

From piezometer data

Control measures and cost

(4) OUTPUT/RESULTS

Print summary

Save summary

Display results

(5) SYSTEM

Quit

Shell to DOS

Install

b. The five selections of the main menu may be accessed by simply moving the cursor to the position beneath the desired selection. Figure 15 presents the main menu as it appears on the screen.

c. The explanation and description of this program will include many figures presenting menu screens and output. The input data and output data are from Stovall, MS Levee Station 77/38+00. A complete listing of the interactive solution of this problem is included in Appendix A.

Each of the calculation options in LEVSEEP requires certain input for execution of that option. Table 1 provides an overview of the required input for each calculation option. Each of the calculation options (i.e., initial conditions, from piezometric data, berm control measure and cost, riverside blanket control and cost, cutoff control and cost, and relief well control and cost) requires geotechnical properties data as input. In addition, the "from piezometer data" option requires piezometer location and readings input. To obtain a plot of the levee, the cross-section information is required. To obtain a piezometer plot, both the cross-section data and piezometer data are required.

Input/Edit Data from File

This main menu option requires the user to indicate if data will be new or from an existing file. The submenus of this option are (a) new, (b) load file, (c) save file, and (d) print file. Figure 16 displays the submenu options under this main menu héading. To select one of the subroutines under the site data heading, the user should position the curser beneath the INPUT/EDIT DATA

```
          *********    LEVSEEP    *********
                  UNDERSEEPAGE ANALSYSIS
     *********        v3.0 JUNE 91      *********
-----------------------------------------------------------------------

             To Select Menus Use:  arrow keys  ;
 ________________________________________________________________________
|    INPUT/EDIT DATA     |CALCULATIONS|   OUTPUT/   |      SYSTEM       |
|   FILE   |  KEYBOARD   |            |   RESULTS   |                   |
|________________________________________________________________________|

Options:
                                 <<<  to select option
                                      enter Highlighted letter
```

Figure 15. LEVSEEP main menu

Table 1
Input Data Requirements for LEVSEEP

Calculation Options	Cross Section	Geotechnical Properties	Piezometer Properties	Control Measure Unit Costs
Initial conditions	optional	required	N.A.	N.A.
From piezometer data	optional	required	required	N.A.
Berm control and cost	optional	required	N.A.	optional
Riverside blanket control and cost	optional	required	N.A.	optional
Cutoff control and cost	optional	required	N.A.	optional
Relief well control and cost	optional	required	N.A.	optional

from FILE option heading and enter the highlighted letter for the desired option. LEVSEEP allows the user to enter data by accessing an existing or previously created file or by interactive means. LEVSEEP will display screens for input in the interactive mode. The user need only to access the screens and enter the requested information on each screen. The user may call an existing or previously created file by selecting the Load File option. The user will then be required to specify the filename to be accessed. This

```
                 *********    LEVSEEP    *********
                     UNDERSEEPAGE ANALSYSIS
               *********     v3.0 JUNE 91     *********
-------------------------------------------------------------

                To Select Menus Use:   arrow keys  ;

|     INPUT/EDIT DATA      |CALCULATIONS|   OUTPUT/   |    SYSTEM    |
|    FILE     |  KEYBOARD  |            |   RESULTS   |              |


Options:
        New                                 <<<  to select option
        Load file                                enter Highlighted letter
        Save file
        Print file
```

Figure 16. Main menu option INPUT/EDIT DATA from FILE

file may then be edited under the INPUT/EDIT DATA from KEYBOARD menu option. Once all input/edit tasks have been completed, the user may save the input file by selecting the Save File option. The user may also print the input file by accessing the Print File option.

Input/Edit Data from Keyboard

This main menu option consists of the following input options: cross section, geotechnical properties, piezometric properties, and control measures. Figure 17 displays the submenu options under this main menu heading. The cross section option allows the user to input data that define the geometry of the levee section. The geotechnical properties option affords the user the ability to input specific geotechnical properties of the section that are critical to the analysis of the levee section. The piezometer properties option consists of locations and readings submenus. The control measures option provides the user with several control measure options which are discussed in detail in subsequent paragraphs. Those options include berm, riverside blanket, cutoff, and relief well.

Cross section

Immediately following the selection of this option, the user will be asked "How many points?" It should be noted that this request is for the total number of points. These points will define the geometry of the levee section. Input consists of points that constitute lines on the cross section. The levee cross section is idealized into a levee, top blankets, foundation layers, etc., and these "lines" are entered as the cross-section geometry. Points should be input for changes in slope or direction or at other significant features. Each point is defined by a pair of x and y coordinates. Figure 18 reveals the input/edit screen that the user will see. When the data entry is complete, the

```
          *********     LEVSEEP    *********
              UNDERSEEPAGE ANALSYSIS
     *********       v3.0 JUNE 91     *********
---------------------------------------------------------------


            To Select Menus Use:  arrow keys  ;
 ________________________________________________________________
|   INPUT/EDIT DATA      |CALCULATIONS|   OUTPUT/   |    SYSTEM   |
|  FILE     |  KEYBOARD  |            |   RESULTS   |             |
|________________________________________________________________|

Options:
       X - section                     <<<  to select option
       Geotechnical properties              enter Highlighted letter
       Piezometric properties
       Control measures
```

Figure 17. Main menu option INPUT/EDIT DATA from KEYBOARD with options

```
                    CROSS SECTION DATA INPUT SCREEN

LINE#    X       Y         lINE#    X       Y        LINE#    X      Y
-----   ---     ---        -----   ---     ---       -----   ---    ---
1      -1600   164.5       1       110     170       1       1201   164.5

1      -400    164.5       1       190     167.5     1       1600   164.5

1      -390    168         1       200     164.5     2       -800   153

1      -125    178         1       400     164.5     2       200    153

1      -10     201.3       1       401     155       2       201    151

1      10      201.3       1       1200    157       2       400    151


POINT NUMBER :  1                           <Esc> exit screen
SCREEN  1  OF  2                            <^PgUp> previous screen
                                            <^PgDn> next screen
```

Figure 18. Cross-section data input/edit screen

user can view the cross section to verify that the data entry is correct. This step may be accomplished through the "OUTPUT/RESULTS" main menu heading suboption "Display Results." Simply select "D" and then "G" on the following screen, and finally "S" on the next screen. At this time, the geometry can be viewed on the screen. If a mouse is present, the user may point to locations on the screen and view the coordinates at any location. In this manner the input geometry can be verified. Figure 19 provides an example geometry display output. Under this option, the user may also elect to send this output to a plotter if he so desires.

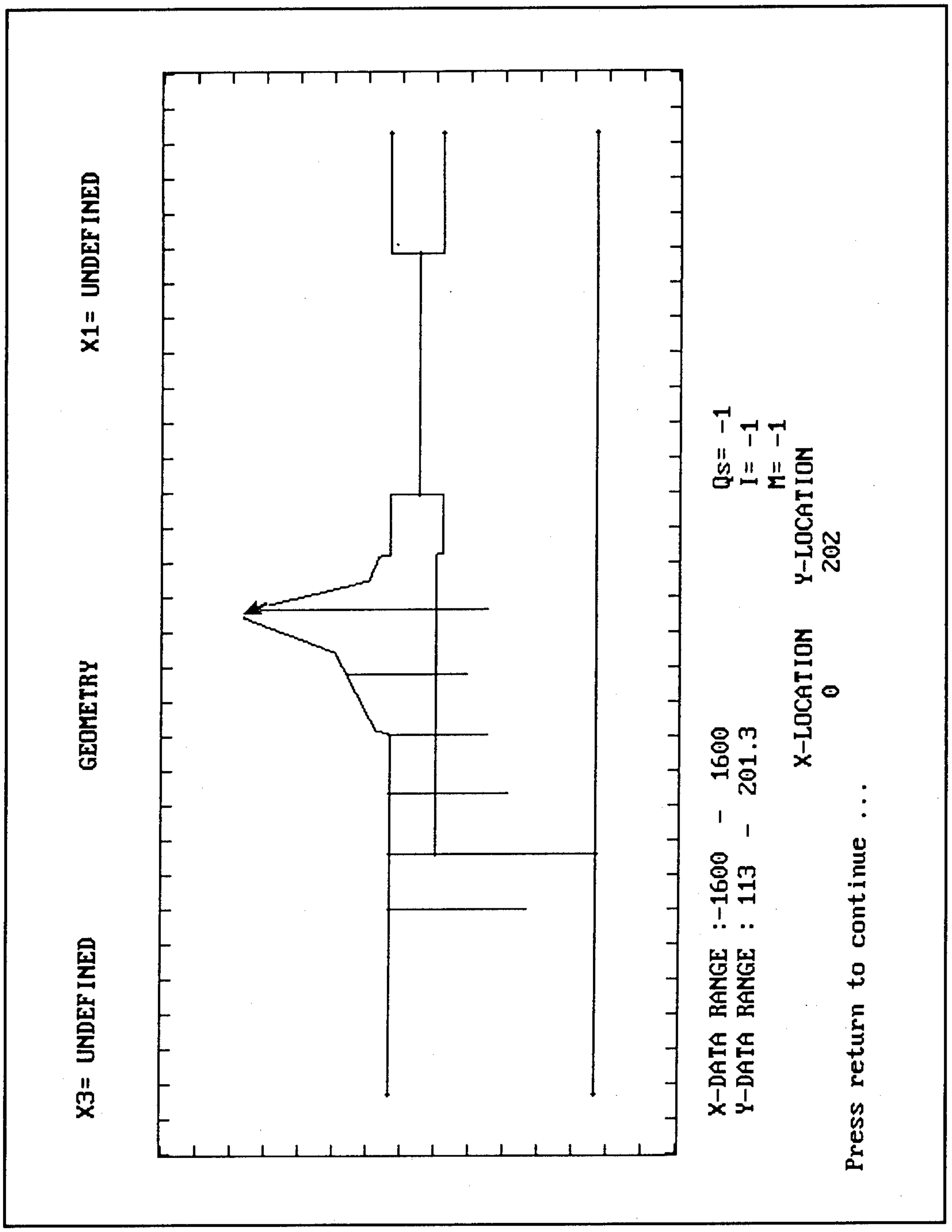


Figure 19. Example of geometry display

Geotechnical properties

Figure 20 displays the input/edit screen that the user will see under this option. Information identifying the project, levee section, toe elevation, toe offsets, head, entrance and exit conditions, unit weight, and stratigraphy is entered on this screen. Figure 21 displays the screen that will immediately follow. This screen requests substratum permeability data. This information is followed by a request for landside and riverside permeability data. Figure 22 provides a look at this screen.

Piezometric properties

LEVSEEP queries the user for locations and readings under this option. LEVSEEP queries for the number of piezometers for which data will be entered. Figure 23 reveals the piezometer locations data input/edit screen. The other option under this menu is the piezometer readings option. This option requests information from the user as illustrated in Figure 24. The user is then required to indicate the date for which calculations are being requested.

Control measures

This submenu option allows the user to input data related to various control measures. The control submenus under this option are for (a) berm, (b) riverside blanket, (c) cutoff, (d) relief well, and (e) unit cost. Figure 25 shows the options under the control measures menu options. Once the control measure option has been selected, data may be entered for all the control measure options. LEVSEEP will display screens for input in this interactive mode in a continuous manner. The user need only to follow the screens and enter the requested information. The subroutines under the control measures succeed in the following order:

a. Berm control measure input (Figure 26).

b. Riverside blanket control input (Figure 27).

c. Relief well control input (Figure 28).

d. Berm unit cost input (Figure 29).

e. Cutoff default input/edit unit cost decision screen (Figure 30).

f. Cutoff unit cost input screen (Figure 31).

g. Riverside blanket unit cost input screen (Figure 32).

```
GEOTECHNICAL DATA INPUT/EDIT SCREEN

PROJECT NAME   STOVALL, MISSISSIPPI

STATION #  77/38+00       LANDSIDE TOE ELEV   164.5

LANDSIDE TOE OFFSET  400           RIVERSIDE TOE OFFSET   200

NET HEAD ON LEVEE  29.8          RIVERWARD EXTENT OF TOP STRATUM  200

LANDWARD EXTENT OF TOP STRATUM  400          ENTRANCE  open

EXIT  blocked        SUBMERGED WEIGHT   50


NUMBER OF LAYERS COMPOSING PERVIOUS FOUNDATION   1

NUMBER OF LAYERS COMPOSING LANDSIDE STRATA    1

NUMBER OF LAYERS COMPOSING RIVERSIDE STRATA   1
                                              <Esc> exit screen
```

Figure 20. Geotechnical data input/edit screen

```
SUBSTRATUM PERMEABILITY DATA (AVERAGED)

COEFFICENT OF PERMEABILITY                    .25

EFFECTIVE THICKNESS OF PERVIOUS SUBSTRATUM   40

ACTUAL DEPTH OF PERVIOUS SUBSTRATUM          40









                                              <Esc> exit screen
```

Figure 21. Substratum permeability data input/edit screen

```
LANDSIDE AND RIVERSIDE PERMEABILITY DATA (AVERAGED)

EFFECTIVE THICKNESS OF LANDSIDE TOP STRATUM   11.5

PERMEABILITY OF LANDSIDE TOP STRATUM          .00015

EFFECTIVE THICKNESS OF RIVERSIDE TOP STRATUM  13.5

PERMEABILITY OF RIVERSIDE TOP STRATUM         .00002

EFFECTIVE THICKNESS FOR UPLIFT                11.5

TOP STRATUM THICKNESS                         14




                                              <Esc> exit screen
```

Figure 22. Landside and riverside permeability data input/edit screen

```
PIEZOMETER DATA INPUT SCREEN / LOCATIONS

POINT     PIZO      PIZO      TIP     TOP
NUMBER    STATION   OFFSET    ELEV    ELEV
------    -------   -------   ----    ----
B-3       38+00     20u/s     140     200

B-4       38+00     200d/s    145     175

B-5       38+00     400d/s    140     165

B-6       38+00     600d/s    135     165

B-7       38+00     985d/s    130     165


 POINT NUMBER :  1                  <Esc> exit screen
 SCREEN  1  OF  1                   <^PgUp> previous screen
                                    <^PgDn> next screen
```

Figure 23. Piezometer locations data input/edit screen

```
                    PIEZOMETER DATA INPUT SCREEN

POINT        DATE OF       PIZO        POOL
NUMBER       READING       READING     READING
------       -------       -------     -------
B-3          05/09/1973    175.3       178.2

B-4          05/09/1973    174.1       178.2

B-5          05/09/1973    172.4       178.2

B-6          05/09/1973    167.3       178.2

B-7          05/09/1973    172.5       178.2


 POINT NUMBER :   1                              <Esc> exit screen
 SCREEN  1  OF  1                                <^PgUp> previous screen
                                                 <^PgDn> next screen
```

Figure 24. Piezometer readings data input/edit screen

```
BERM (B)
RIVERSIDE BLANKET (R)
CUTOFF (C)
WELL (W)
```

Figure 25. Control measures option menu screen

h. Relief well unit cost input screen (Figure 33).

i. Berm calculation input screen (Figure 34).

Figures 26 through 34 provide the user with a look at these input screens.

Berm control input. The user is required to supply information pertaining to the allowable upward gradients for the levee and berm as well as the slopes of the levee and berm. Figure 26 shows the berm control measure input/edit screen.

Riverside blanket control input. This option requires the user to input data related to the upward gradient, slope of the blanket toe, and average slope of the riverside levee. Figure 27 reveals the riverside blanket input/edit screen.

Relief well control input. The relief well input/edit screen requires the user to input the allowable upward gradient, well radius, pipe diameter, coefficient of pipe roughness, viscosity of water, and well top height. Figure 28 reveals the relief well input/edit screen.

Berm unit cost. This screen displays the default unit costs of various types of berms. Berms supported by LEVSEEP include an impervious berm, a semipervious berm, a sand berm, a pervious berm with a collector pipe, a typical Rock Island District berm, and an unspecified berm. The user may accept the default value or enter his own values for any of the berms. Figure 29 shows the default berm unit costs.

Cutoff unit cost. Figure 30 reveals the cutoff default unit costs. This screen asks the user to specify if he wishes to use the default unit costs. If the user answers "no," then he must input new cutoff unit cost data. Prior to entering the new unit cost data, he will be asked to specify the number of cutoff layer costs. Once a response is received, LEVSEEP presents the cutoff unit cost input screen shown in Figure 31. Answering affirmatively to the aforementioned querry facilitates progression to the riverside blanket unit cost input screen.

Riverside blanket unit cost. This screen reveals the default unit cost for the riverside blanket. The user may accept these data or enter his own unit cost data. Figure 32 provides a look at this screen.

Relief well unit cost. This screen provides default costs for drilling, pipe, well screen, filter, backfilling, well cover, development, and testing. The user may specify stainless steel, galvanized steel, or PVC plastic for the pipe and well screen. Figure 33 reveals the relief well unit cost screen.

Berm calculations input. This screen provides the user with the minimum and maximum standard widths of berms. Also provided is the minimum berm width for the Rock Island District. Figure 34 provides a view of this screen.

```
BERM CONTROL MEASURE INPUT

FACTOR OF SAFETY FOR BERM
                              INPUT HERE WILL CAUSE PROGRAM TO CALCULATE
                              LEVEE LANDSIDE TOE ALL. UPWARD GRADIENT

LEVEE LANDSIDE TOE ALLOWABLE UPWARD GRADIENT  .3

BERM LANDSIDE TOE ALLOWABLE UPWARD GRADIENT  .8

LANDSIDE SLOPE OF LEVEE  .076

SLOPE AT BERM TOE  .25




                                        <Esc> exit screen
```

Figure 26. Berm control measure input/edit screen

```
RIVERSIDE BLANKET CONTROL INPUT
BLANKET LANDSIDE TOE ALLOWABLE UPWARD GRADIENT .7

SLOPE AT TRIANGULAR RIVERSIDE BLANKET TOE  .25

RIVERSIDE LEVEE AVERAGE SLOPE .19




                                        <Esc> exit screen
```

Figure 27. Riverside blanket control measure input/edit screen

```
RELIEF WELL CONTROL INPUT

SAFETY FACTOR FOR WELL                 INPUT HERE WILL CAUSE PROGRAM TO CALC
                                       LEVEE LANDSIDE TOE ALL. UPWARD GRADIENT

LEVEE LANDSIDE TOE ALLOWABLE UPWARD GRADIENT  .53

EFFECTIVE WELL RADIUS 1

INSIDE WELL PIPE DIAMETER  .67

COEFFICIENT OF PIPE ROUGHNESS  .0001
                               stainless steel .... 0.00005
                               galvanized steel ... 0.0006
                               plastic, pvc ....... 0.0001

VISCOSITY OF WATER  .0000121

% REDUCTION OF SEEPAGE FLOW BENEATH LEVEE  1

WELL TOP HEIGHT  .33                          <Esc> exit screen
```

Figure 28. Relief well control measure input/edit screen

```
BERM UNIT COST INPUT

UNSPECIFIED BERM      1.3

IMPERVIOUS BERM       1.3

SEMIPERVIOUS BERM     1.3

SAND BERM             3.75

PERVIOUS BERM WITH A COLLECTOR PIPE  3.75

ROCK ISLAND BERM      3.75




                                              <Esc> exit screen
```

Figure 29. Berm unit cost screen

```
                         CUTOFF COST MENU

  USE DEFAULTS yes


  $ 3.00 ABOVE 65 FEET

  $ 8.00 BELOW 65 FEET







                                          <Esc> exit screen
```

Figure 30. Cutoff default unit cost decision screen

```
                        CUTOFF INPUT SCREEN
 DEPTH     COST     DEPTH     COST     DEPTH     COST     DEPTH     COST
---------------  ---------------  ---------------  ---------------








 POINT NUMBER :  1                          <Esc> exit screen
 SCREEN  1  OF  1                           <^PgUp> previous screen
                                            <^PgDn> next screen
```

Figure 31. Cutoff unit cost input screen

```
                RIVERSIDE BLANKET UNIT COST INPUT
BLANKET UNIT COST                  1.2




                                             <Esc> exit screen

        $/CU YD
```

Figure 32. Riverside blanket unit cost input/edit screen

```
                RELIEF WELL UNIT COST INPUT
DRILLING THROUGH TOP STRATUM       20

DRILLING THROUGH FOUNDATION        16

RISER PIPE                         30          stainless steel .... 80.00
                                               galvanized steel ..: 40.00
                                               plastic, pvc ....... 30.00

WELL SCREEN                        85          stainless steel .... 125.00
                                               galvanized steel ... 75.00
                                               plastic, pvc ....... 85.00

FILTER                             12

BACKFILLING                        400

WELL COVER                         300

WELL DEVELOPMENT AND TEST          1000        <Esc> exit screen
```

Figure 33. Relief well unit cost input/edit screen

```
BERM CALCULATION INPUT

MINIMUM STANDARD CE BERM WIDTH  150

MAXIMUM STANDARD CE BERM WIDTH  400

MINIMUM ROCK ISLAND BERM WIDTH  20

                                        <Esc> exit screen
```

Figure 34. Berm calculations input screen

Calculations

This main menu option allows the user to obtain computations from LEVSEEP. The submenus of this option are for (a) initial conditions, (b) control measures and cost, and (c) from piezometer data.

Figure 35 shows the options under the CALCULATIONS menu heading. LEVSEEP will provide the results of computations on the screen for the user. Some selections require the user to input additional data to complete these computations. This additional input will be discussed under the description of the respective option that requires such input. To select one of the subroutines under the CALCULATIONS heading the user should position the curser beneath the CALCULATIONS option heading and enter the highlighted letter for the desired option. The main menu option CALCULATIONS is presented in Figure 35.

Initial conditions

Immediately following the selection of this option, LEVSEEP will calculate and provide the user with results of those computations. Figure 36 reveals the output that is displayed. The results include values of the effective length of the riverside blanket in feet (x_1), the distance from the landside toe to the

```
          *********    LEVSEEP    *********
              UNDERSEEPAGE ANALSYSIS
       *********       v3.0 JUNE 91     *********
----------------------------------------------------------------------

              To Select Menus Use:  arrow keys  ;
 ___________________________________________________________________
|     INPUT/EDIT DATA     |CALCULATIONS|  OUTPUT/  |     SYSTEM      |
|    FILE    |  KEYBOARD  |            |  RESULTS  |                 |
|___________________________________________________________________|

Options:
        Initial conditions              <<<  to select option
        Control measures & cost              enter Highlighted letter
        Piezometer data
```

Figure 35. Main menu option CALCULATIONS with submenu options

```
PROJECT NAME : STOVALL, MISSISSIPPI
STATION      : 77/38+00

                         INITIAL CONDITIONS
                         ------------------

X1 =    199.61 FT
X3 =   2048.18 FT
M  =   0.0105
I  =   1.8637
Qs =     154.20 GPM/100 FT

HO    =    21.43 FT
$     =   0.0140460
?
```

Figure 36. Initial conditions calculations output

effective seepage exit in feet (x_3), the slope of the hydraulic grade line (M), the upward gradient at the landside toe ($i = h_o / z_t$), the total amount of seepage in gallons per minute (gpm) passing beneath the levee per 100 ft of levee station (Q_s), the hydrostatic head in feet beneath the top stratum at the landside toe of levee without seepage control measures (h_o), and the dimensionless shape factor ($).

Control measures and cost

Selection of this menu option is followed by the option submenu shown in Figure 37. The options under the control measure and cost heading consist of berm, riverside blanket, cutoff, and well. For each these control measures, LEVSEEP will calculate the effective seepage entrance and exit distances, the quantity of seepage per 100 ft of levee width, the gradient (all except well design), and the associated cost of that control measure.

```
BERM (B)
RIVERSIDE BLANKET (R)
CUTOFF (C)
WELL (W)
```

Figure 37. Berm control measure input/edit screen

Berm calculations. Accessing this control measure option allows the user to specify the type of berm that will be analyzed. The types of berms for which calculations can be performed include impervious, semipervious, pervious with a collector pipe, sand, and a typical Rock Island District berm. This menu can be seen in Figure 38. The user is required to specify which berm type will be analyzed. Calculations for the berm type specified are immediately presented on the screen. Figure 39 shows the results of one such calculation. Pressing enter at the prompt produces the berm cost calculation screen shown in Figure 40 to appear on the screen.

The following prompts may occur for analysis of berms:

a. When a creep ratio is needed for standard Corps calculations, the user is asked for the soil type with a default creep ratio of 8.5 for that of very fine sand or silt.

b. If the berm fails the thickness check, a message is printed indicating that the berm failed.

c. Refer to blanket responses if a blanket is calculated.

d. If a Rock Island berm option is selected, the user is asked for a creep ratio with a default value of 10.

```
                BERM SELECTION MENU

 1. IMPERVIOUS BERM
 2. SEMIPERVIOUS BERM
 3. PERVIOUS BERM WITH COLLECTOR PIPE
 4. SAND BERM
 5. ROCK ISLAND BERM

 ENTER NUMBER OF CHOICE ===>
? 1
```

Figure 38. Berm selection menu screen

```
PROJECT : STOVALL, MISSISSIPPI
STATION : 77/38+00

             OUTPUT DATA FOR BLANKET ANALYSIS
             --------------------------------

X1 =  4718.33 FT
X3 =  2048.18 FT
M  =  0.0039
I  =  0.7014
Qs =     58.03 GPM/100 FT

XR  =  4733.90 FT
LB  =   800.00 FT
KB  =  0.00001000 CM/SEC
ZB  =     3.56 FT
VRB =    10559.53 CU YD/100 FT
?
```

Figure 39. Berm analysis output screen

```
              BERM COST CALCULATION
              ---------------------

IMPERVIOUS BERM
 VB          =    15726.09 CU YD/100 FT
 UNIT COST   = $       1.30 /CU YD
 TOTAL COST  = $   20443.91 /100 FT LEVEE STATION
?
```

Figure 40. Berm cost calculation screen

Riverside blanket analysis. Selection of this menu option results in the query "Is there a borrow pit? (Y/N)." If the user responds "Y," then LEVSEEP responds with a request for top stratum thickness in the borrow pit. The user is then asked to input a pair of input parameters. The user must specify either LB and KB (required length of artificial riverside blanket and permeability of artificial riverside blanket, respectively), LB and ZB (required length of riverside blanket and thickness of artificial riverside blanket, respectively), or KB and ZB. For this example problem, the first option is specified. The user will then be prompted to enter a value for the artificial blanket width (LB). The user will then be prompted for a value of permeability for the artificial blanket. Figure 41 reveals the results of the computations that follow. Figure 42 reveals the blanket cost calculation screen that is displayed next. There are many combinations of data entry under this option. While it would be impractical to discuss all of the possible combinations, several example problems are included in this manual for the user's benefit.

```
PROJECT : STOVALL, MISSISSIPPI
STATION : 77/38+00

                  OUTPUT DATA FOR BLANKET ANALYSIS
                  --------------------------------

X1 =  4718.33 FT
X3 =  2048.18 FT
M  =  0.0039
I  =  0.7014
Qs =      58.03 GPM/100 FT

XR  =  4733.90 FT
LB  =   800.00 FT
KB  =  0.00001000 CM/SEC
ZB  =      3.56 FT
VRB =     10559.53 CU YD/100 FT
?
```

Figure 41. Riverside blanket analysis output screen

```
                 BLANKET COST CALCULATION
                 ------------------------

VRB          =     10559.53 CU YD/100 FT
UNIT COST  = $          1.20 /CU YD
TOTAL COST = $     12671.44 /100 FT OF LEVEE STATION
```

Figure 42. Riverside blanket cost calculation screen

In general, when calculating blankets, the user is asked for the following responses:

a. In order to determine blanket type, the user is asked to indicate the presence of a borrow pit.

b. The value of x_r is checked against L_1. If x_r or L_B is less than the distance to the river, calculations are valid for this case and the calculations will continue.

c. If a borrow pit is indicated, a value of z_{br} must be chosen for the borrow pit.

d. In the case of no natural riverside top stratum, one of two blankets may be calculated: (1) uniform thickness or (2) triangular section.

e. At some point in the calculations, the user is prompted for some combination of L_B, k_B, or k_{Bb} and z_B or z_{Bb} input. When given a choice, the user enters the menu option of the variable or variables that he would input. The others are calculated when possible.

f. When choosing the input L_B and k_b or k_{Bb} or z_B or z_{Bb}, the user may enter trial values in order to observe the effects on the other results. Having decided on a value, the user enters <RETURN> and proceeds to enter his choice for the remainder of the calculations.

Cutoff analysis. Accessing this option will allow the user to receive the results of a cutoff analysis. The user will be asked to specify the cutoff depth ratio as seen in Figure 43. Upon entering these data, the user will receive the results of calculations for the effective length of the riverside blanket, the distance from the landside levee toe to the effective seepage exit, the slope of the hydraulic grade line, the upward gradient at the landside toe, and the seepage quantity per 100 ft of levee station. Figure 44 reveals the output screen for the cutoff analysis. This screen will be followed immediately by the cutoff cost calculation screen as shown in Figure 45.

Relief well analysis. Selection of this menu option results in an instantaneous display of the results of the analysis. These results include well spacing, depth of penetration, well discharge, and cost per 100 feet of levee station. Figure 46 reveals the results of one such analysis. LEVSEEP prints the results of relief well analyses at 12.5 percent increments of penetration from 25 to 100 percent penetration. The most economical well configuration is conveniently positioned at the end of the display.

```
                    CUTOFF ANALYSIS
                    ---------------

 DC/D : CUTOFF DEPTH/DEPTH RATIO ===>
? .95
```

Figure 43. Cutoff depth ratio screen

```
 PROJECT : STOVALL, MISSISSIPPI
 STATION : 77/38+00
                  OUTPUT DATA FOR CUTOFF ANALYSIS
                  -------------------------------

 DC/D = .95

 X1 =   199.61 FT
 X3 =  2048.18 FT
 M  =  0.0106
 I  =  1.7995
 Qs =    145.82 GPM/100 FT
?
```

Figure 44. Cutoff analysis screen

```
                CUTOFF COST CALCULATION
                -----------------------

 DEPTH =    52.00
 COST  = $    15600.00 /100 FT OF LEVEE STATION
?
```

Figure 45. Cutoff cost calculation screen

```
STATION : 77/38+00

      OUTPUT DATA FOR RELIEF WELL ANALYSIS
      ------------------------------------

X1 =   199.61 FT
X3 =  2048.18 FT
M  = UNDEFINED
I  = UNDEFINED
Qs =     154.03 GPM/100 FT
J  =  0  %

  P              ASEL             WBAR           QW               COST
  ft             ft               ft          gal/100 ft            $
-----          ------           ------           ----          -----------
  0.25          94.90            10.00          370.26           3719.86
  0.38         125.86            15.00          469.62           3253.71
  0.50         149.86            20.00          599.83           3109.57
  0.63         168.42            25.00          665.85           3102.43
  0.75         182.73            30.00          708.29           3168.63
  0.88         193.89            35.00          771.33           3277.65
  1.00         202.68            40.00          782.30           3414.31

  0.63         168.42            25.00          665.85           3102.43
?
```

Figure 46. Relief well analysis output screen

Piezometric data

Accessing this option initiates calculations based on piezometer data for this levee section. The output as seen in Figure 47 consists of calculations to include the effective length of riverside blanket (x_1), effective seepage exit distance (x_3), slope of the hydraulic grade line (M), exit hydraulic gradient (I), and the seepage quantity (Q_s).

```
PROJECT NAME : STOVALL, MISSISSIPPI
STATION      : 77/38+00

          FROM PIEZOMETER DATA
          --------------------

X1 =    351.67 FT
X3 =   1560.01 FT
M  =   0.0055
I  =   0.7399
Qs =      80.38 GPM/100 FT

H  =     13.70 FT
l1 =    420.00 FT
h1 =     10.80 FT
l2 =    200.00 FT
h2 =      9.60 FT
H0 =      8.51 FT
S  =    951.67 FT
?
```

Figure 47. Piezometer data calculation results

Output/Results

Under this main menu heading, LEVSEEP provides the user with a host of output options. The options under this menu can be seen in Figure 48. The user may elect to print a summary of all calculations. This summary may be printed to the screen or to a printer. The user may save the summary to file for later manipulation. The third option under this heading allows the user to display the output graphically. The number of display options is based on the number of calculations that the user has specified. When the "Display" option is accessed, the user will see the screen in Figure 49. The display options for which calculations have been performed will be listed on this screen for display. Options for which calculations have not been performed will not appear on the screen.

```
                    *********    LEVSEEP    *********
                         UNDERSEEPAGE ANALSYSIS
                 *********      v3.0 JUNE 91     *********
---------------------------------------------------------------------

                    To Select Menus Use:  arrow keys  ;
 ___________________________________________________________________
|   INPUT/EDIT DATA      |CALCULATIONS|   OUTPUT/   |    SYSTEM     |
|   FILE    |  KEYBOARD  |            |   RESULTS   |               |
|___________________________________________________________________|

Options:
        Print summary                 <<<  to select option
        Save summary                       enter Highlighted letter
        Display results
```

Figure 48. Output/results main menu option screen

```
   CURRENT AVAILABLE DISPLAY OPTIONS ARE:


                (G)EOMETRY
                (I)NITIAL CONDITIONS
                (B)ERM
                (R)IVER BLANKET
                (C)UTOFF
                RELIEF (W)ELL
                (P)IEZOMETER

                SELECT LETTER
                < Esc > TO ABORT ROUTINE
```

Figure 49. Display options screen

Once the user selects a display option, he will see the screen shown in Figure 50. The user may then choose to plot the display to the screen, to file, or to a plotter. Figure 51 provides the display screen for the geometry option, and Figure 52 provides the display screen for the initial conditions. A complete complement of all the display screens are included with the example problem in Appendix A.

System

This main menu option provides the user with the ability to quit the program shell and go to DOS, or change default installation parameters. Figure 53 presents the main menu options found under the SYSTEM heading. Selecting "Quit" sends the user out of LEVSEEP while "Shell to DOS" allows the user to leave LEVSEEP, perform DOS operations, and then return to LEVSEEP by typing "Exit" at the DOS prompt. The default installation can be seen in Figure 54. These parameters may be changed through the "Install" option.

```
                    PLOT DIRECTION MENU
PLOT TO:         (S)CREEN

                 (F)ILE

                 HP (P)LOTTER

                           S

FILE NAME


NOTE:  ONLY ONE OPTION CAN BE PERFORMED AT A TIME



                                         <Esc> exit screen
      SELECT OPTION BY ENTERING LETTER
```

Figure 50. Plot direction menu

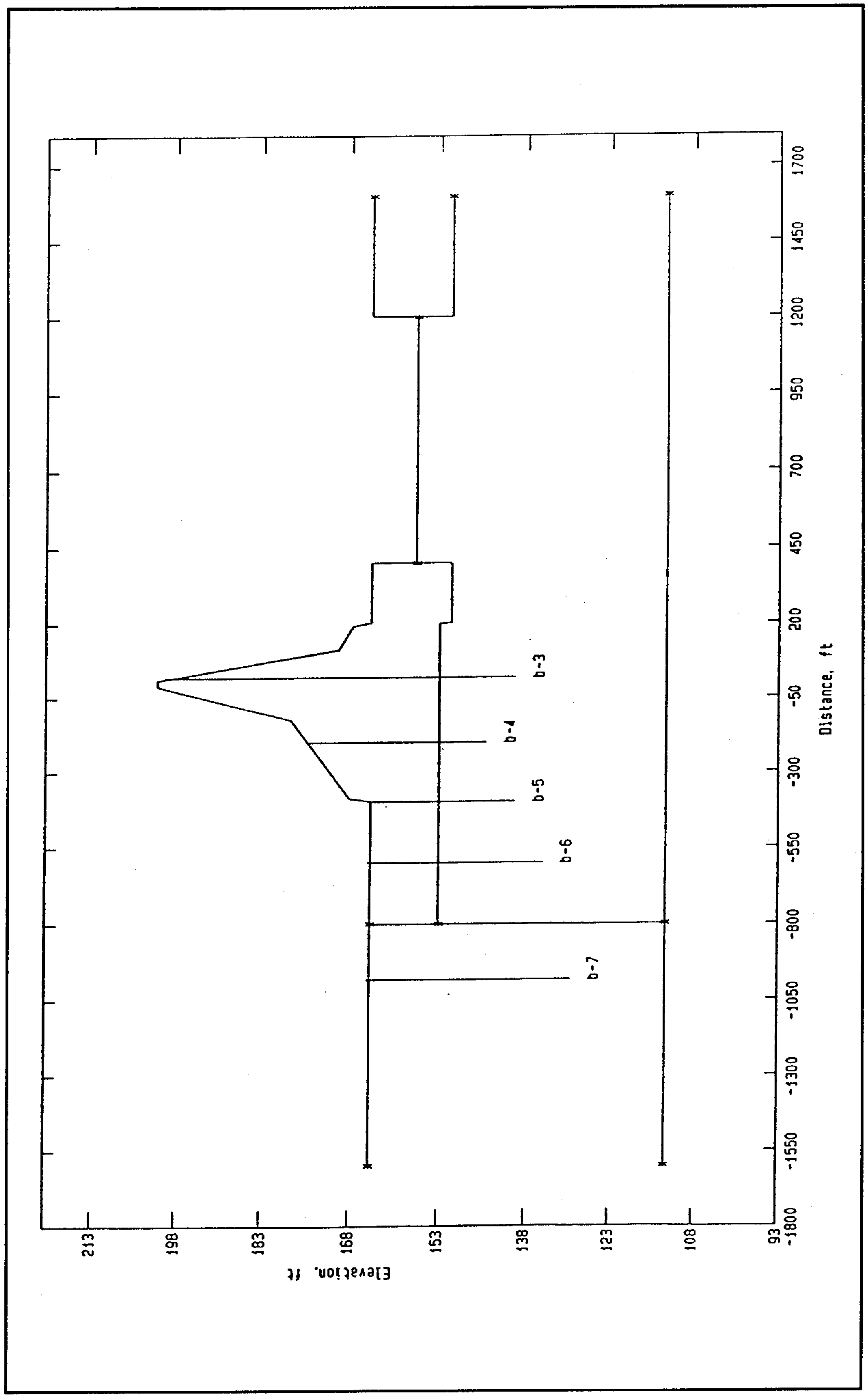


Figure 51. Example geometry display screen

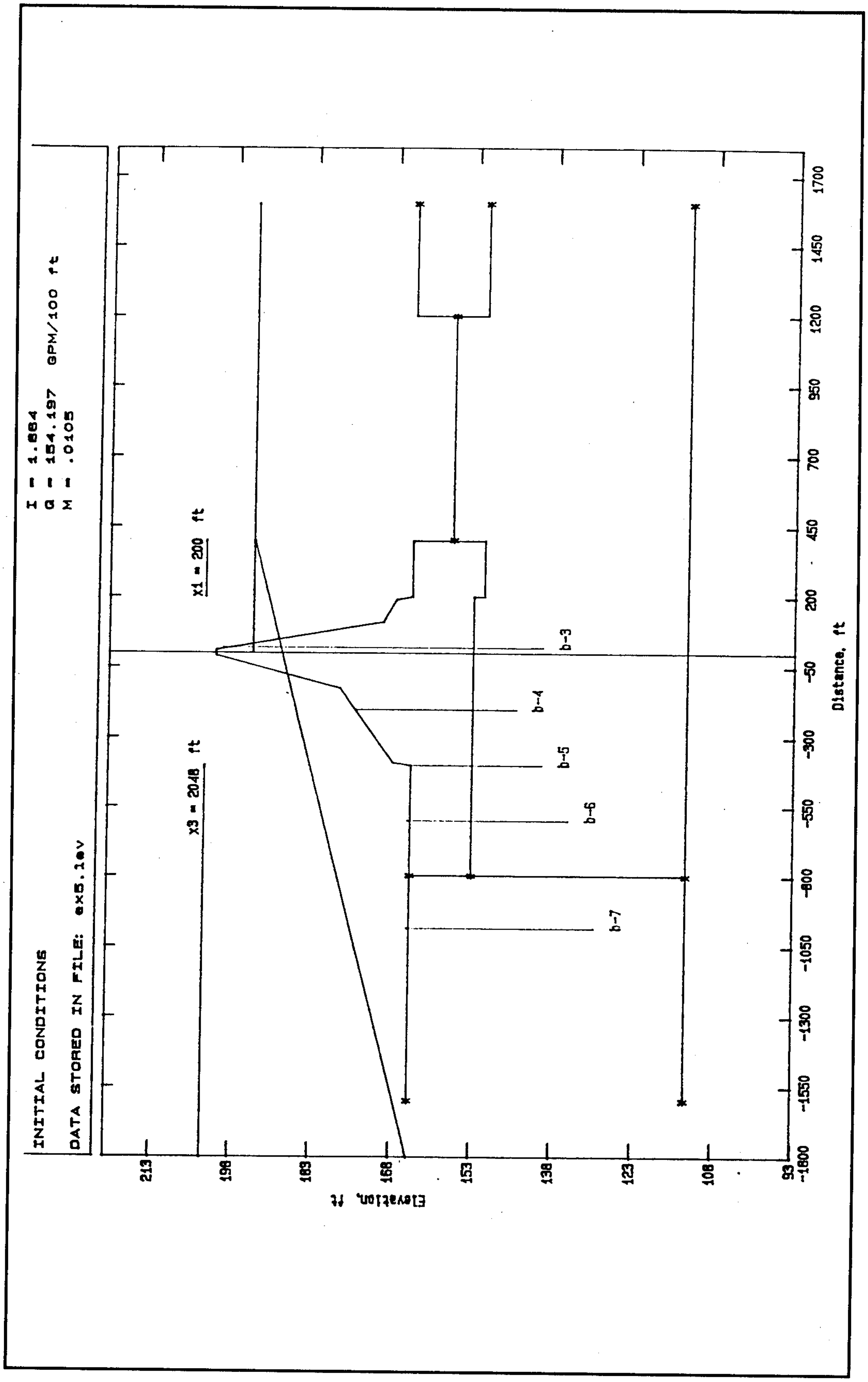


Figure 52. Example initial conditions display screen

```
        *********     LEVSEEP    *********
           UNDERSEEPAGE ANALSYSIS
    *********      v3.0 JUNE 91     *********
----------------------------------------------------------------------------

           To Select Menus Use:  arrow keys  ;
  ________________________________________________________________
 |     INPUT/EDIT DATA     |CALCULATIONS|   OUTPUT/  |   SYSTEM    |
 |   FILE    |  KEYBOARD   |            |   RESULTS  |             |
 |_________________________________________________________________|

Options:
        Quit                          <<<  to select option
        Shell to DOS                       enter Highlighted letter
        Install
```

Figure 53. System main menu option screen

```
            INSTALLATION MENU


PORT FOR PLOTTER           com1

PORT FOR PRINTER           lpt1

UNITS                      ft

DEFAULT DIRECTORY



                                          <Esc> exit screen

      COM1, COM2, COM3
```

Figure 54. Install option menu screen

4 Analysis of Prototype Levee Reaches at Magnolia Levee, Ohio

Two levee reaches are selected for analysis as case studies to demonstrate the application potential and limitation of the LEVSEEP model. These reaches were identified as having sufficient data to conduct the analysis with foundation conditions appropriate for program application and illustration. The two case studies are for levees located in the Huntington District. A Huntington District, Magnolia Levee, site location map is presented in Figure 55. The two case studies analyzed and presented here are for the cases of:

a. Two-layer foundation with top stratum, both riverside and landside to be referred to as section 1;

b. One-layer foundation with no top stratum, either riverside or landside to be referred to as section 2.

Site Description

The Magnolia Levee drainage district is located in the Muskingum watershed of southeastern Ohio. The levee is located 6.5 miles east of Bolivar dam on Sandy Greek of the Tuscarawas River, a tributary of the Muskingum River. The levee protects the town of Magnolia, Ohio. The total length of the levee is 4,877 ft with crest elevations that vary between el 966 and 976.[1] The levee is monitored by thirteen open tube piezometers that are strategically located along the length of the embankment. The levee has no relief wells.

Soil Conditions

Soil profiles for the site are shown in Figures 56, 57, and 58 with location of these sections presented in Figure 59. The site is generally underlain by

[1] Elevations are in feet mean sea level.

cohesionless soils that mainly consist of fine to medium sand and gravel. A discontinuous top stratum with a thickness that ranges from 4 to 8 ft and consists of silt and clay/sandy clay exists at the south reach of the levee east of the intake channel between sta 5+00 and 10+00. This layer is absent for the remainder of the levee site as may be inferred from sections presented in Figures 57 and 58.

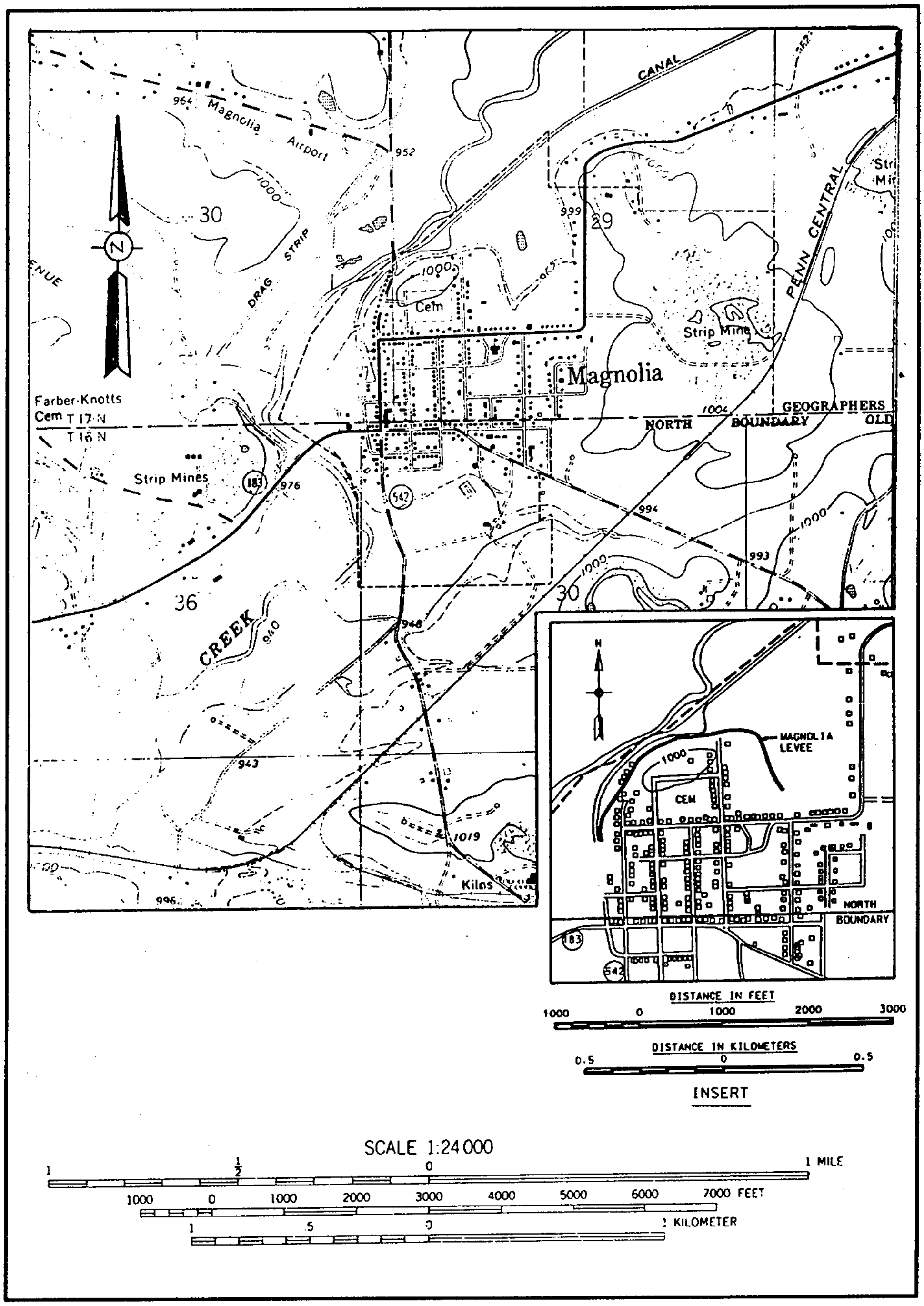


Figure 55. Site location map: Magnolia Levee, Huntington District

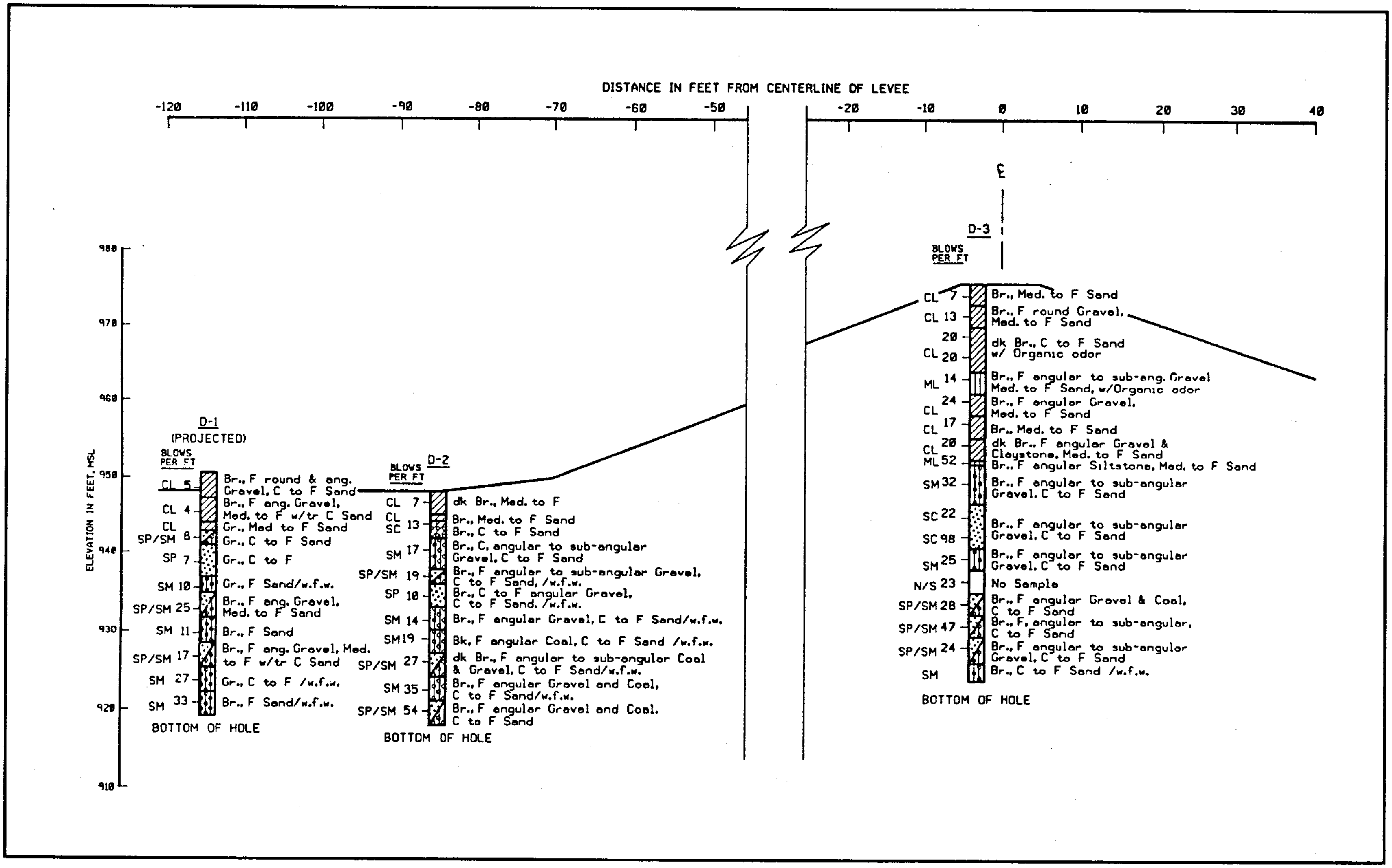


Figure 56. Soil profile between sta 5+00 and 10+00

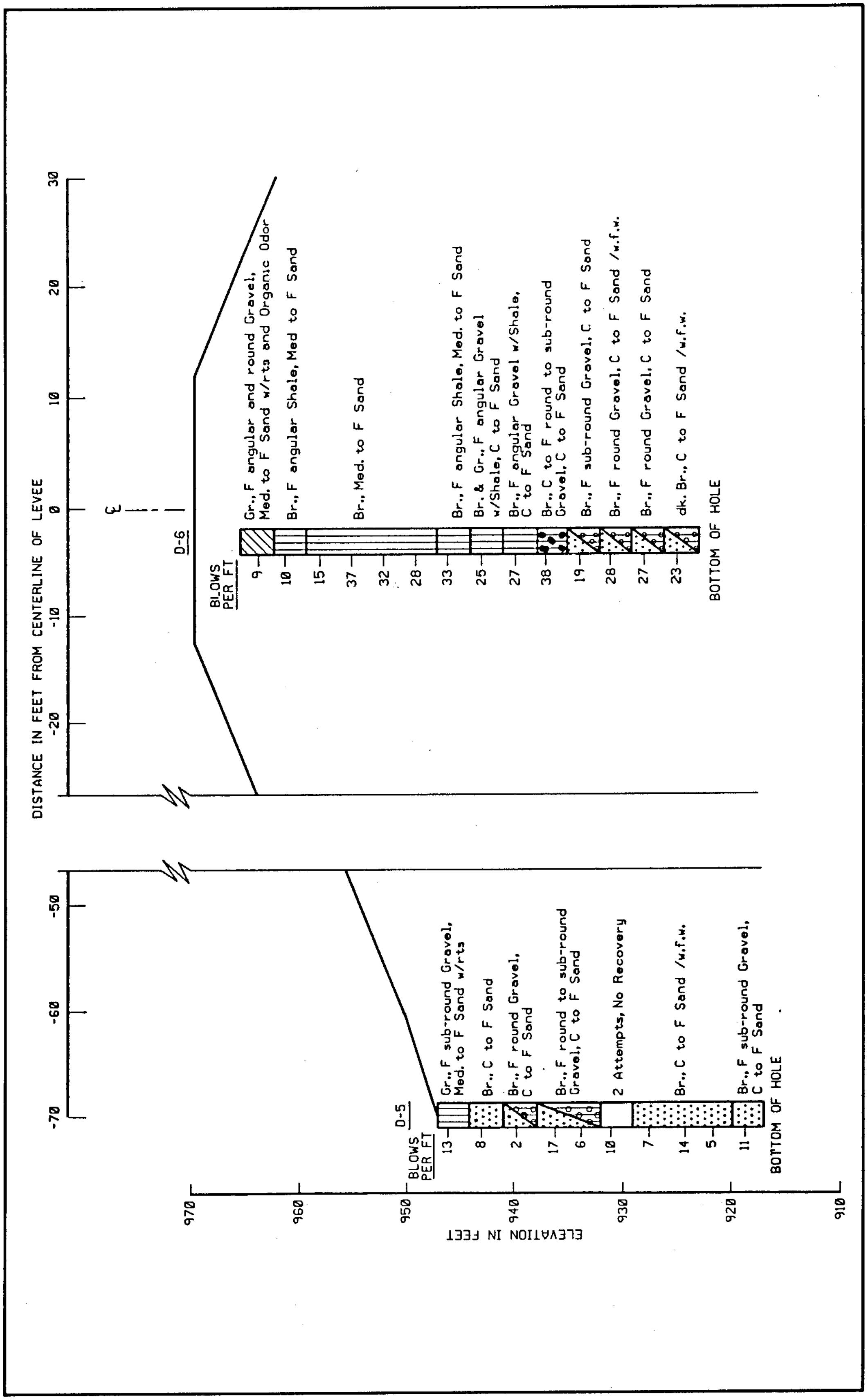


Figure 57. Soil profile between sta 20+00 and 25+00

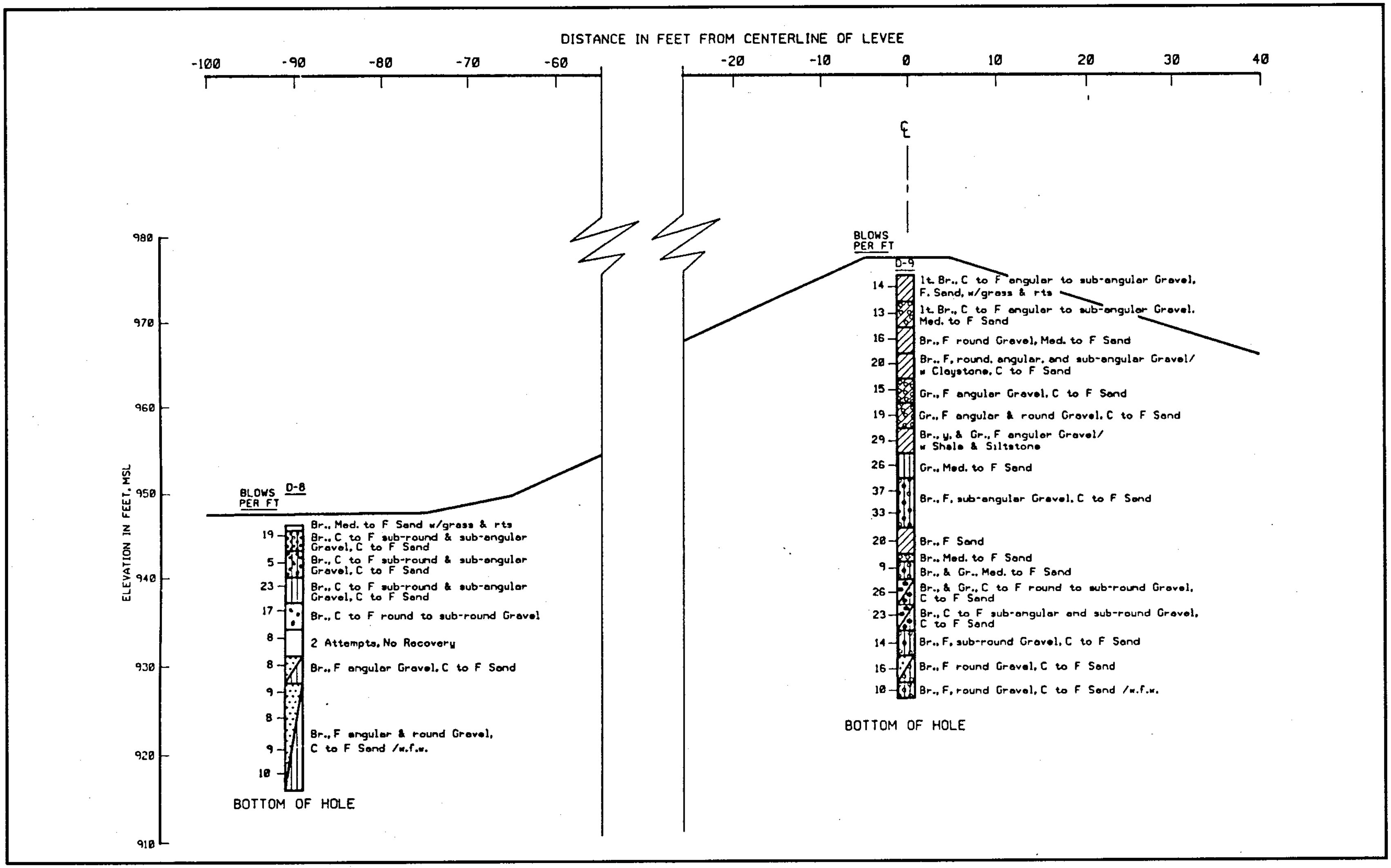


Figure 58. Soil profile between sta 40+00 and 45+00

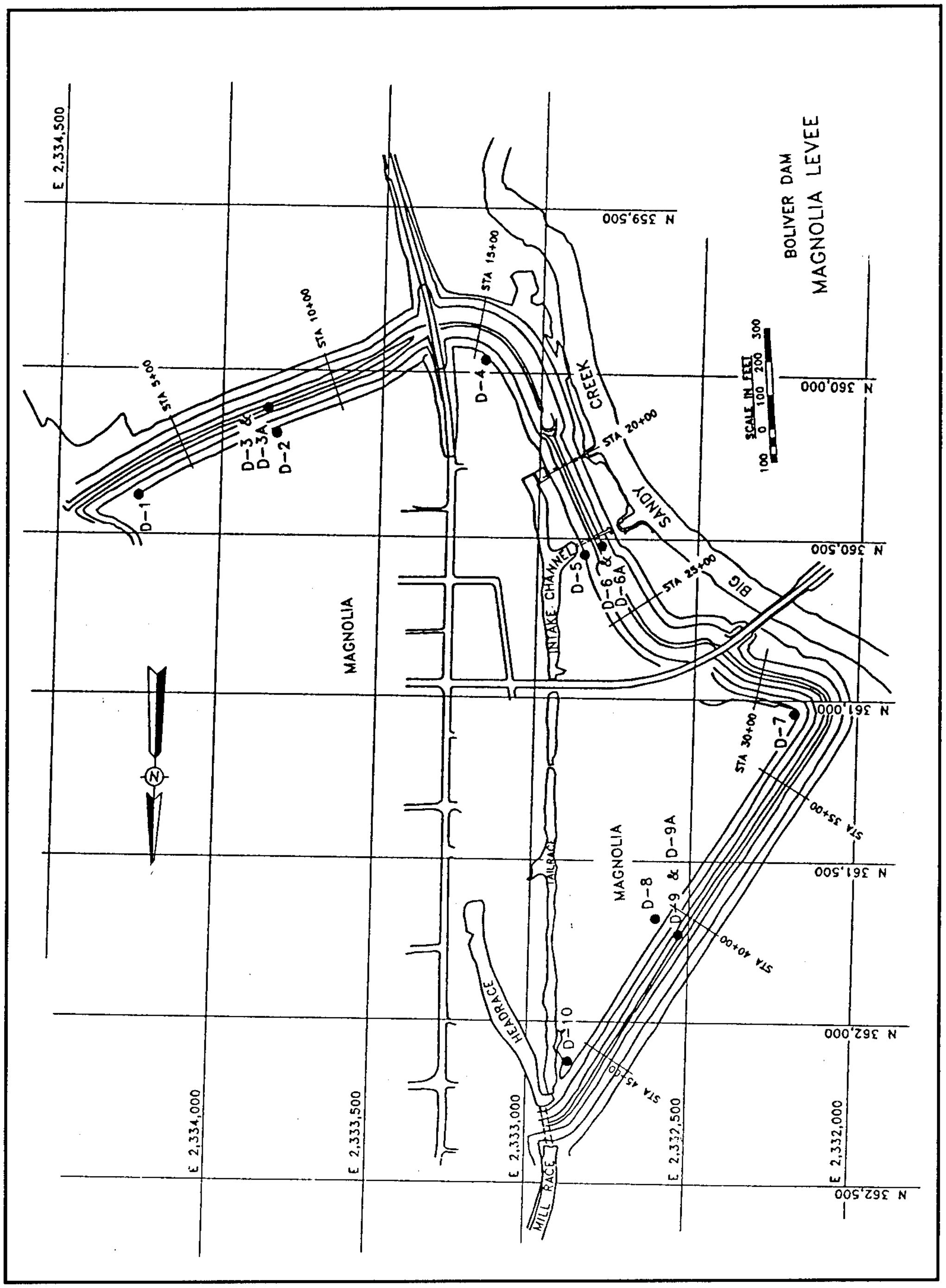


Figure 59. Piezometer location plan and site layout - Magnolia Levee

Seepage Conditions

Thirteen open tube piezometers (D-1 through D-10, D-3A, D-6A, and D-9A) are monitored to evaluate the pore water conditions in the foundation and embankment of the levee. These piezometers were installed in 1988. The tips of all piezometers were placed above el 931; therefore the Pool of Record (P.O.R) of 1991, which occurred at el 950.1, was the only event during which piezometric responses were observed. Approximately 16 readings from each piezometer were obtained during this event as presented in the Periodic Inspection Report No. 5, June 1991. In general, fluctuation in piezometer readings when no water is stored against the levee appears to reflect groundwater conditions. Data from piezometers monitored during the P.O.R event and with an assumed tailwater elevation between el 943 and 944.7 are presented as Table 2.

Table 2
Piezometer Data During the P.O.R Event (el 950.1)

Piezometer	Piezometer Elevation (Date: 6/91)
D-1	949.3
D-2	948.8
D-3	948.4
D-4	945.5
D-5	944.7
D-6	948.5
D-7	948.7
D-8	946.2
D-9	948.4
D-10	947.0

Analysis

Two cross sections were considered for the analysis of this site. The first cross section, which will be referred to as section 1, is taken at the location of piezometers D-2, D-3, and D-3A and represents the portion of the site where a top blanket was assumed to be 7 ft thick. The second cross section, which will be referred to as section 2, is taken at the location of piezometers D-5, D-6, and D-6A and represents subsurface conditions with no top blanket. The idealized analyses sections and geometrical parameters are presented in Figures 60 and 61.

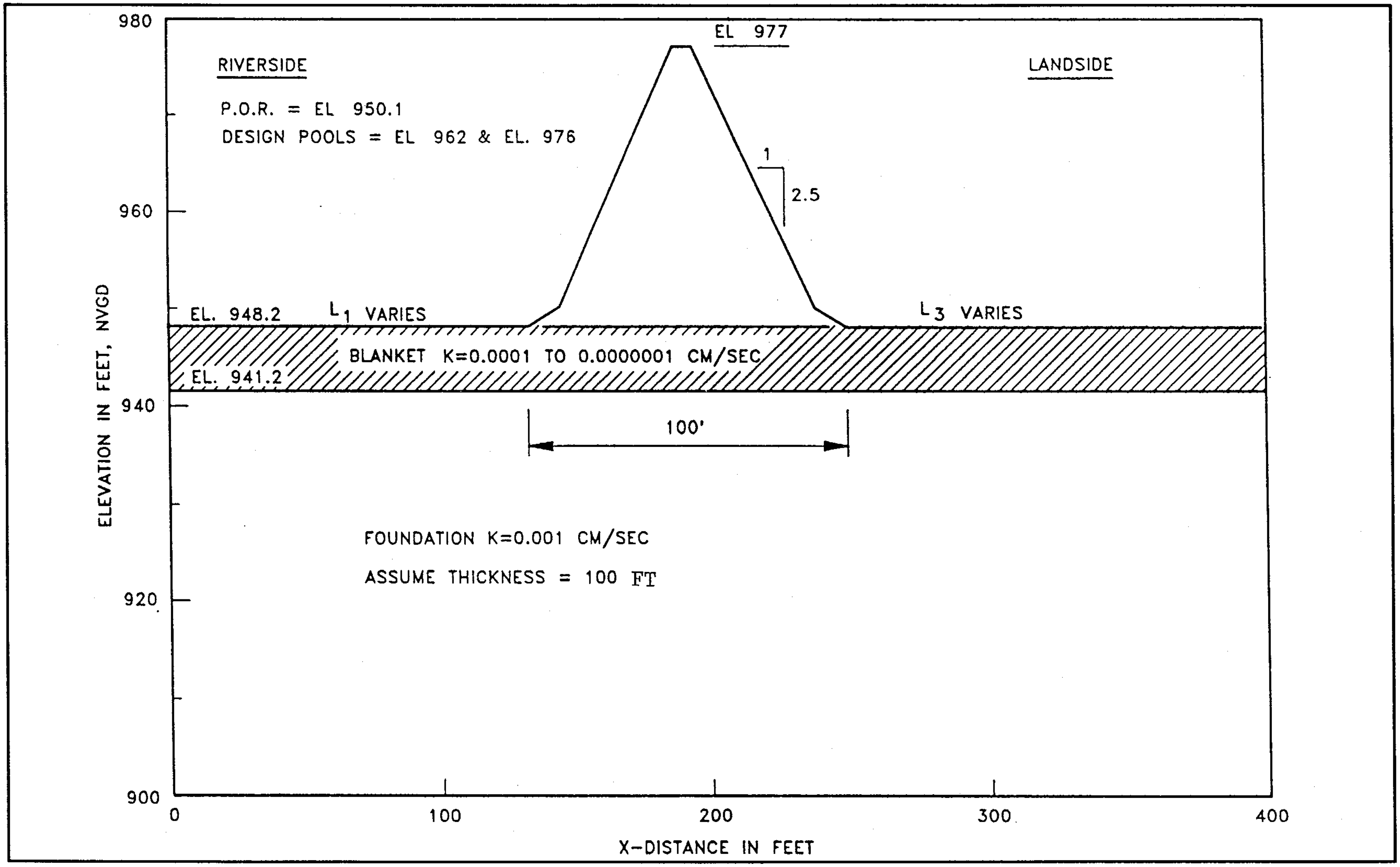


Figure 60. Magnolia Levee - idealized analysis section 1 (between sta 5+00 and 10+00)

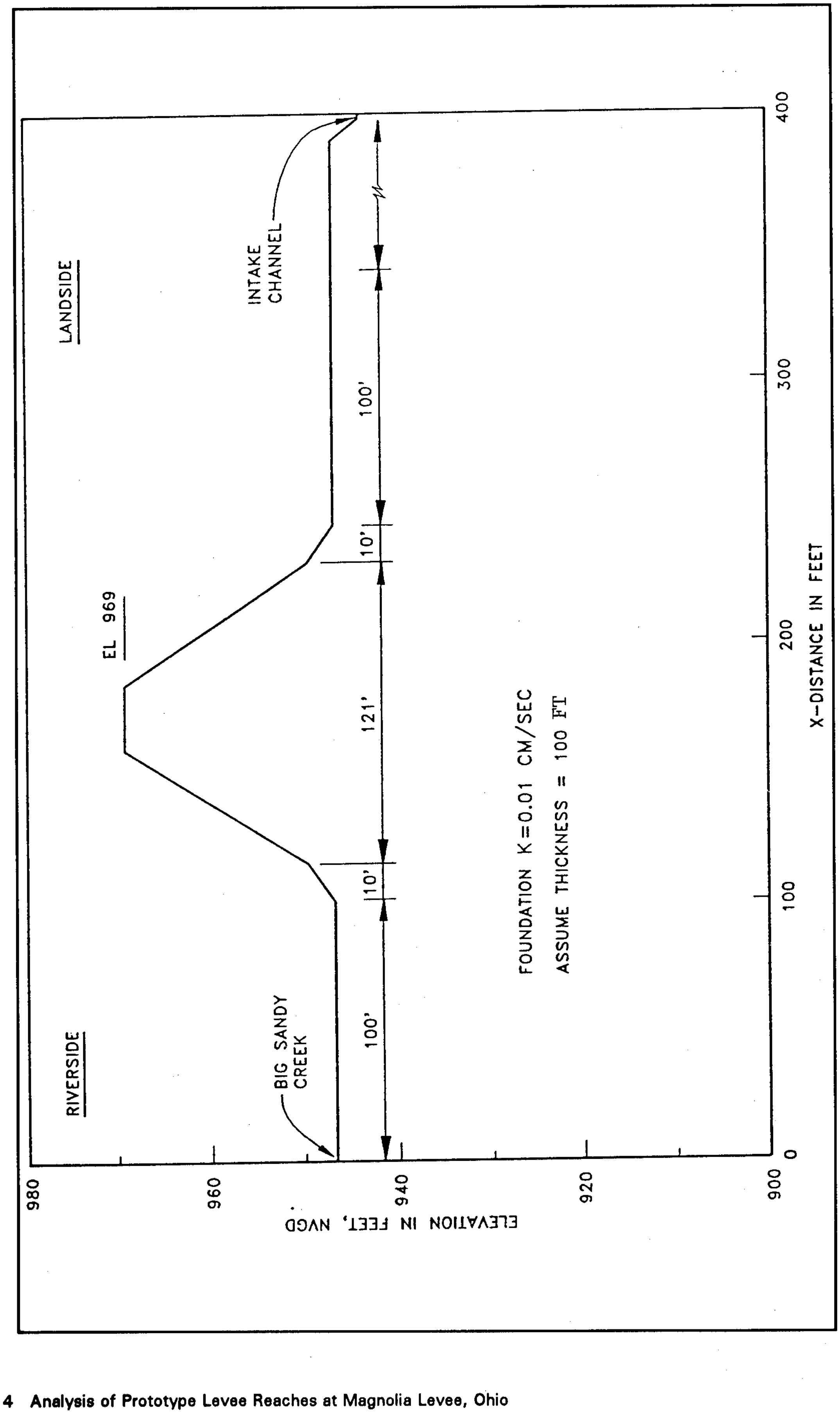


Figure 61. Magnolia Levee - idealized analysis section 2 (between sta 20+00 and 25+00)

The blanket permeability values for the LEVSEEP analyses were assumed to vary between 0.0001 to 0.0000001 cm/sec. The foundation permeability was assumed to be constant and equal to 0.01 cm/sec.

Results and Discussion

Results of the analysis for section 1 are presented in Figure 62 as a function of the permeability ratio k_f/k_b. These data are also summarized in Table 3. The estimated exit hydraulic gradient varied as a function of the assumed blanket length on the riverside and landside. In the case of blanket length equal to 2,000 ft on the riverside and 175 ft on the landside, the value of the exit hydraulic gradient decreased as the permeability ratio (k_f/k_b) is increased, as shown in Figure 62 (sheet 1). For a river pool of el 976 and permeability ratio of 100, the exit hydraulic gradient was on the order of 1.03. As the permeability ratio is increased to 100,000 and the permeability of the top blanket is decreased, the exit gradient was reduced to a value of approximately 0.30. On the other hand, with a blanket length of 200 ft on the riverside and 1,750 ft on the landside assumed, the value of the exit hydraulic gradient increased as the permeability ratio is increased, as shown in Figure 62 (sheets 3 and 4). In case of a river pool elevation of 976, the value of the exit hydraulic gradient ranged from approximately 1.74 for a permeability ratio of 100 to 3.27 for a permeability ratio of 100,000. It is of interest to note that for different pool elevations, the variation in the value of the exit hydraulic gradient was slight in the case of a blanket length of 200 ft on the riverside and 175 ft on the landside, as shown in Figure 62 (sheets 1 and 3). For the case where the blanket length was 2,000 ft on the riverside and 1,750 ft on the landside, the variation in the exit hydraulic gradient was also slight, as shown in Figure 62 (sheets 2 and 4). It should be noted from Figure 62, and from Table 3 that significantly different analysis results for hydraulic gradient are obtained for slightly varied conditions of blanket length and permeability ratio. Such observations emphasize the importance of accurate characterization of the blanket geometrical and hydraulic conditions.

Compared to piezometer D-1 and D-2 readings of el 949.3 and 948.8, analysis from different permeability ratios predicted an average piezometric head of el 949. This piezometric elevation was predicted for a river pool of el 950.1 based on the fact that the pool elevation on the landside coincided with the ground surface.

The use of LEVSEEP for the analysis of section 2, where no top blanket is present, is limited to predictions for the total seepage quantity for initial conditions and control measure analysis. LEVSEEP cannot predict the exit hydraulic gradient for the case where no landside top blanket is present. As indicated in EM 1110-2-1913, the construction of a flow net is required for the analysis in such a situation. Exit hydraulic gradient from flow net was estimated to be approximately 1.0 with a river pool of el 969.

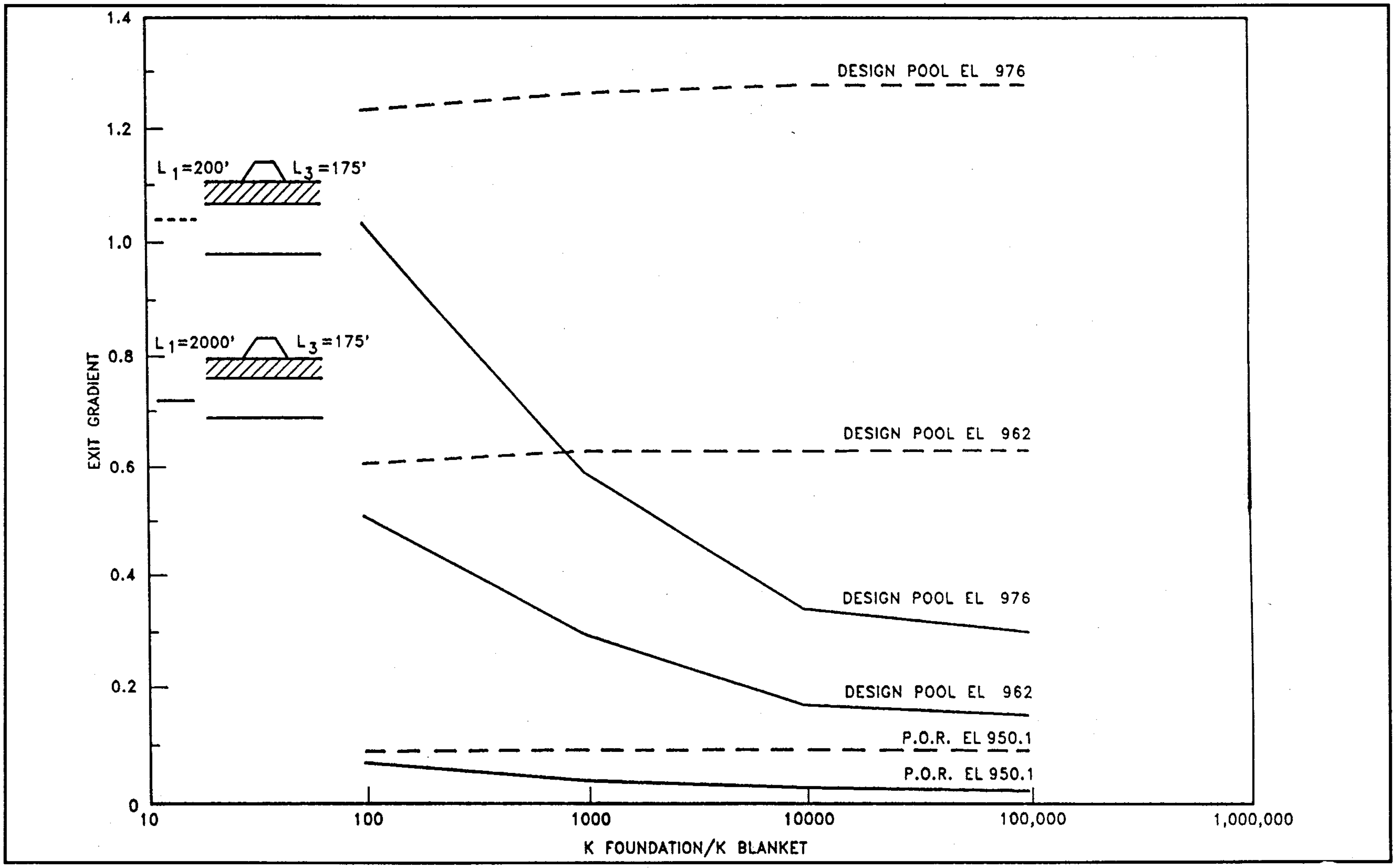


Figure 62. Results of idealized section 1 parameter study - Magnolia Levee (between sta 5+00 10+00) (Sheet 1 of 4)

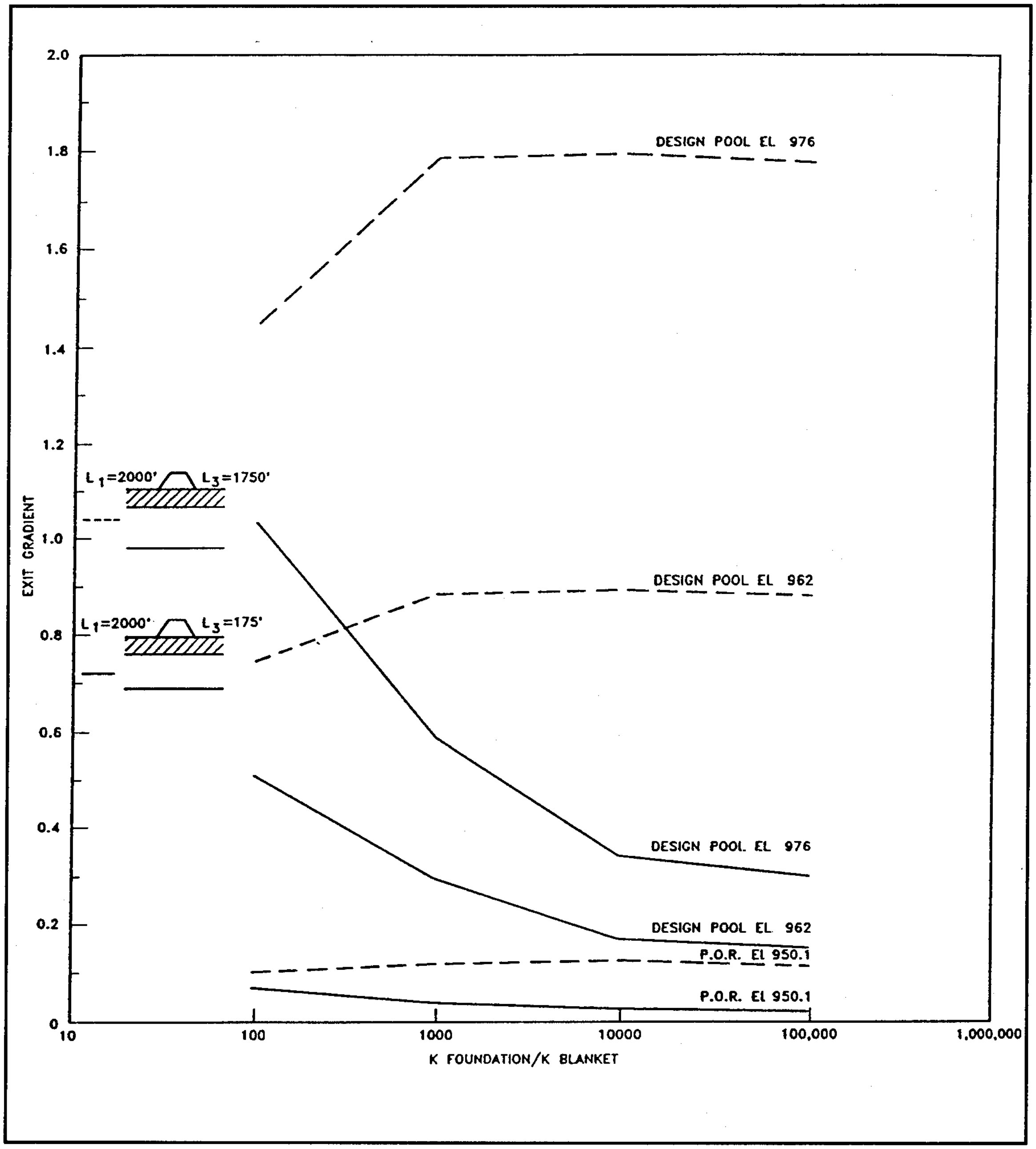


Figure 62. (Sheet 2 of 4)

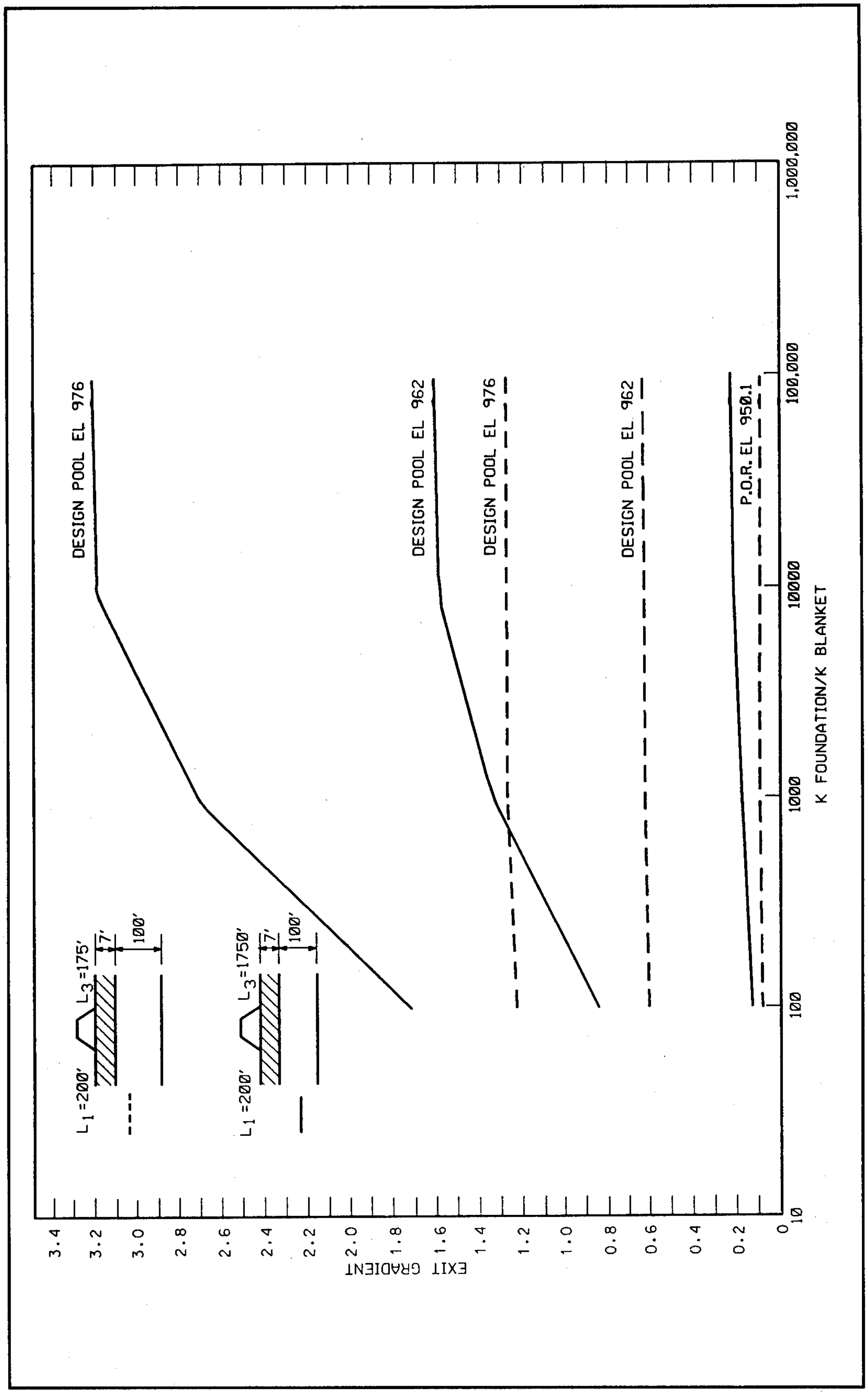


Figure 62. (Sheet 3 of 4)

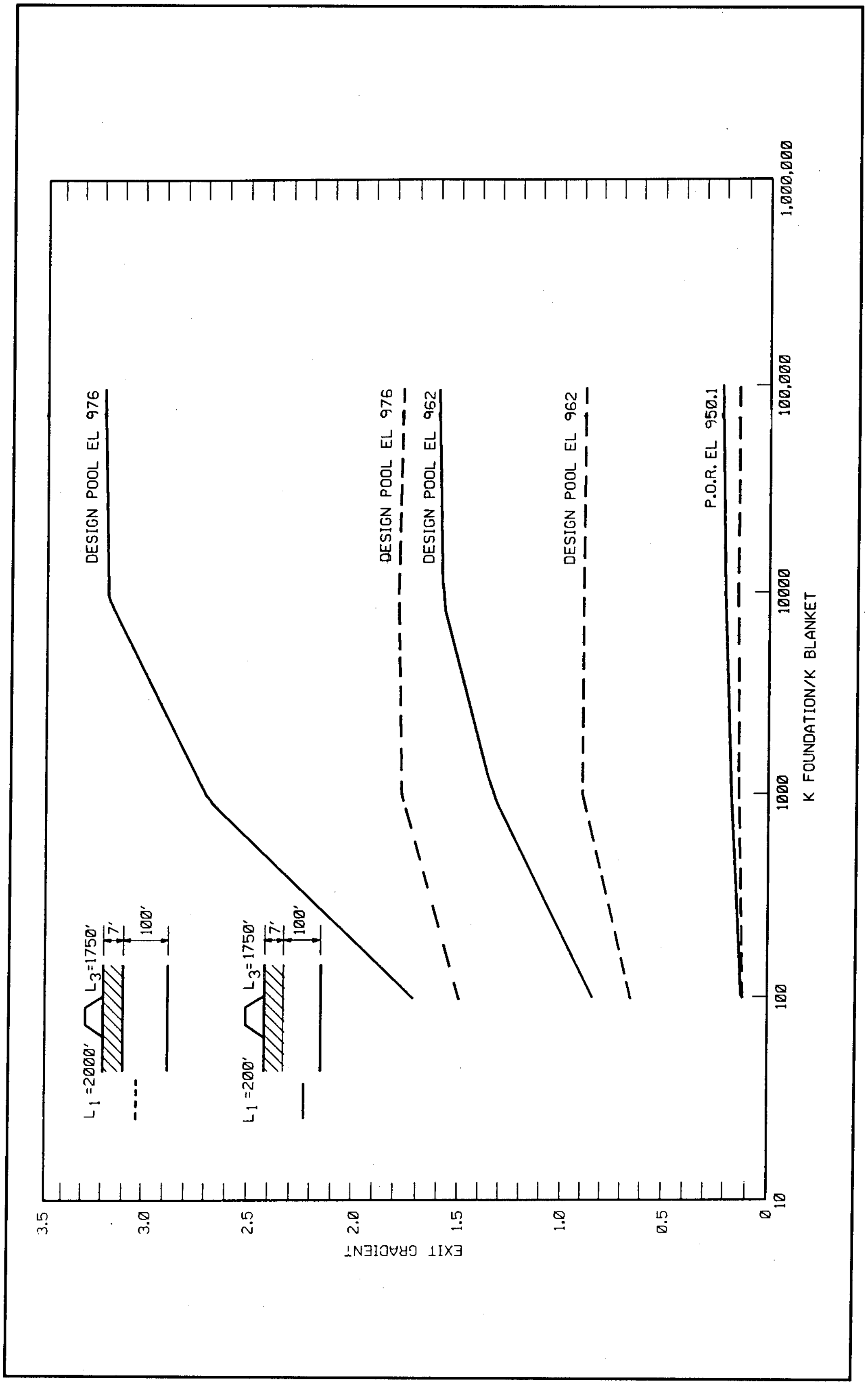


Figure 62. (Sheet 4 of 4)

Table 3
Results of Parameter Study at Magnolia Levee, Ohio, for Varying Permeability Ratios, Blanket Lengths, and Pool Elevations (Section 1 Between Sta 5+00 and 10+00)

L_1 = 2,000 ft L_3 = 175 ft k_f = 0.01 cm/sec

Pool Elevation	Blanket Permeability	Permeability Ratio, k_f/k_b	Exit Hydraulic Gradient, i, From LEVSEEP
950.1	0.0001	100	0.0705
950.1	0.00001	1000	0.0401
950.1	0.000001	10000	0.0233
950.1	0.0000001	100000	0.0206
962.0	0.0001	100	0.5123
962.0	0.00001	1000	0.2913
962.0	0.000001	10000	0.1692
962.0	0.0000001	100000	0.1493
976.0	0.0001	100	1.0320
976.0	0.00001	1000	0.5869
976.0	0.000001	10000	0.3408
976.0	0.0000001	100000	0.3009

(Sheet 1 of 4)

In general, analyses results indicated that potential underseepage problems could occur at the levee under higher pool elevations than have occurred to date. Predicted exit hydraulic gradients for the two sections analyzed are generally above critical and therefore indicate a high probability of piping and boiling to occur in cases where pool river elevations exceed el 962. Boiling may be especially critical where no, or a relatively thin, top blanket is present to provide seepage resistance.

Table 3 (Continued)

L_1 = 200 ft L_3 = 175 ft k_f = 0.01 cm/sec

Pool Elevation	Blanket Permeability, k_b	Permeability Ratio, k_f/k_b	Exit Hydraulic Gradient, i, From LEVSEEP
950.1	0.0001	100	0.0842
950.1	0.00001	1000	0.0866
950.1	0.000001	10000	0.0868
950.1	0.0000001	100000	0.0868
962.0	0.0001	100	0.6114
962.0	0.00001	1000	0.6288
962.0	0.000001	10000	0.6305
962.0	0.0000001	100000	0.6307
976.0	0.0001	100	1.2316
976.0	0.00001	1000	1.2668
976.0	0.000001	10000	1.2702
976.0	0.0000001	100000	1.2705

(Sheet 2 of 4)

Table 3
(Continued)

L_1 = 200 ft L_3 = 1,750 ft k_f = 0.01 cm/sec

Pool Elevation	Blanket Permeability, k_b	Permeability Ratio, k_f/k_b	Exit Hydraulic Gradient, i, From LEVSEEP
950.1	0.0001	100	0.1186
950.1	0.00001	1000	0.1867
950.1	0.000001	10000	0.2185
950.1	0.0000001	100000	0.2233
962.0	0.0001	100	0.8613
962.0	0.00001	1000	1.3560
962.0	0.000001	10000	1.5867
962.0	0.0000001	100000	1.6217
976.0	0.0001	100	1.7352
976.0	0.00001	1000	2.7317
976.0	0.000001	10000	3.1964
976.0	0.0000001	100000	3.2669

(Sheet 3 of 4)

Table 3
(Concluded)

L_1 = 2,000 ft L_3 = 1,750 ft k_f = 0.01 cm/sec			
Pool Elevation	Blanket Permeability, k_b	Permeability Ratio, k_f/k_b	Exit Hydraulic Gradient, i, From LEVSEEP
950.1	0.0001	100	0.1024
950.1	0.00001	1000	0.1219
950.1	0.000001	10000	0.1226
950.1	0.0000001	100000	0.1213
962.0	0.0001	100	0.7439
962.0	0.00001	1000	0.8857
962.0	0.000001	10000	0.8902
962.0	0.0000001	100000	0.8810
976.0	0.0001	100	1.4986
976.0	0.00001	1000	1.7843
976.0	0.000001	10000	1.7932
976.0	0.0000001	100000	1.7749
			(Sheet 4 of 4)

5 Design Applications and Remedial Measures

The computer program LEVSEEP can be used for the analysis of levee underseepage. LEVSEEP can be used to analyze the effects of riverside blankets, landside berms, cutoffs, and relief wells. These control measures can be analyzed and compared as remedial measures. LEVSEEP can provide quantity and cost estimates for use in the design process.

The following general suggestions for the use of control measures are taken from TM 3-424 and EM 1110-2-1913. This information is used to identify the use of control measures and to help LEVSEEP design those control measures. Generally, LEVSEEP can be used for analysis where traditional Corps calculations have been performed.

Control Measures and Criteria for Design

The design of seepage control measures for levees often requires an underseepage analysis without the use of piezometric data and seepage measurements. It should be emphasized that the accuracy obtained from the use of equations is dependent upon the applicability of the equation to the condition being analyzed, the uniformity of soil conditions, and evaluation of the various factors involved. As is normally the case, sound engineering judgment must be exercised in determining soil profiles and soil input parameters for these analyses.

It is necessary to make certain simplifying assumptions before making any theoretical seepage analysis. The following is a list of such assumptions and criteria necessary to the analysis set forth in this chapter.

a. Seepage may enter the pervious substratum at any point in the foreshore (usually at riverside borrow pits) and/or through the riverside top stratum.

b. Flow through the top stratum is vertical.

c. Flow through the pervious substratum is horizontal.

d. The levee (including impervious or thick berms) and the portion of the top stratum beneath it are impervious.

e. All seepage is laminar.

In addition to the above, it is also required that the foundation be generalized into a pervious sand or gravel stratum with a uniform thickness and permeability and a semipervious or impervious top stratum with a uniform thickness and permeability (although the thickness and permeability of the riverside and landside top stratum may be different).

The control of underseepage and prevention of sand boils landward of levees founded on deep strata of pervious sands require some measure that will control erosional seepage and reduce excess pressure beneath the landside top stratum to a safe value.

Methods that may be used to control seepage that are supported by LEVSEEP include riverside blankets, relief wells, landside berms, and cutoffs. The choice of a control measure depends upon a number of factors, including the character of the foundation, cost, permanency, availability of right of way, maintenance, and disposal of seepage water. The principles involved in each of these methods of control are quite different. When the pervious substratum is exposed riverward of a levee, an impervious riverside blanket acts to control seepage by increasing the resistance to seepage entry into the pervious substratum, thereby decreasing both seepage flow and excess pressure landward of the levee. An impervious cutoff beneath a levee blocks the passage of seepage beneath the levee even though there is a ready entry for seepage into the pervious foundation through the river channel or riverside borrow pits. Instead of blocking the flow of seepage beneath a levee, relief wells along the landside toe of a levee provide pressure relief and controlled seepage outlets that offer little resistance to flow but at the same time prevent erosion of the soil. A landside berm controls underseepage by increasing the thickness of the top stratum immediately landward of the levee so that the combined weight of the berm and top stratum is adequate to resist the excess uplift pressure, and by increasing the path of seepage flow through the pervious aquifer to the extent that the residual excess pressure at the toe of the berm is no longer critical. The following discussion of each of these control measures provides general guidance (TM 3-424) for selecting control measures. The specific design formulas for these analyses can be found in the engineer publications discussed in Chapter 2 of this report.

Riverside Blankets

An impervious riverside blanket can be used to reduce the intensity of seepage and pressures landward of a levee where the pervious substratum is,

or is nearly, exposed riverward of the levee. Such blankets are particularly adapted to situations where no top stratum exists riverward of the levee or where most of the natural top blanket has been removed in borrow operations. The primary purpose of a riverside blanket is to increase the distance from the levee to the point of seepage entry, thereby reducing both seepage and landward pressures. To place riverside blankets relatively impervious soils can be hauled in and compacted, or abatis dikes can be constructed, or willow growth encouraged to promote silting of borrow pits.

Landside Seepage Berms

A landside berm can be used to control seepage if the thickness of the top stratum immediately landward of the levee is increased so that the weight of berm plus top stratum is sufficient to resist uplift pressures beneath the top stratum. A properly designed berm will be of such width that the excess head beneath the top stratum at the toe of berm is no longer critical, or the area of possible rupture of the top stratum is removed a sufficient distance from the levee as to no longer endanger it. A landside berm also affords some protection against possible sloughing of the landside slope of the levee as a result of seepage.

Berms can be used to control seepage efficiently where the landside top stratum is relatively thin and uniform or where no landside top stratum is present. However, they are not very feasible where the top stratum is relatively thick and high uplift pressures develop as the thickness and width of berm required to reduce upward gradients to those recommended herein would be excessive. Where the landside top stratum is irregular, berms will force the point of seepage emergency farther from the levee, but concentrations of seepage and sand boils may still develop at thin spots in the top stratum at the berm toe. Where a levee is founded on thin top stratum and thick clay deposits lie a short distance landward of the levee, the seepage berm should be of sufficient width and thickness to cover the near edge of the thick clay if practicable; otherwise, the berm will tend to concentrate the seepage in the area between the berm toe and the thick clays.

Where a levee is founded on a very thin top stratum and is subject to concentration of seepage and the formation of sand boils, the safety of the levee can be improved by adding a landside seepage berm constructed of material borrowed landward of the berm. The near edge of such borrow pits should be about 50 to 100 ft from the berm toe, and borrow operations should be controlled so as to ensure uniform removal of all of the top stratum down to sand. This additional berm will permit seepage to emerge uniformly instead of in the form of sand boils. (The combined base width of levee and seepage berm should provide an adequate creep ratio.) Although this method of seepage control has certain disadvantages, in that it may remove valuable land from cultivation and create undesirable waterfilled ponds, it may be better in some situations than the removal of top strata riverward of a levee for borrow, thereby creating a source of seepage close to the levee.

Seepage berms should generally have a slope of 1 on 50 or steeper to ensure drainage. However, if the berm is constructed after the levee has caused the foundation to consolidate fully, a slope of 1 on 75 can be used.

Cutoffs

Where practicable, the most positive method of underseepage control is to cut off all seepage beneath a levee by means of an impervious barrier which will eliminate both excess substratum pressures and the problem or seepage water landward of the levee. However, completely cutting off pervious strata 80 to 200 ft deep along extensive reaches of levees is not economically feasible. The installation of partially penetrating cutoffs will not reduce seepage and excess pressures significantly unless the cutoff penetrates 95 percent or more of the pervious aquifer. However, shallow cutoffs along the riverside toe of levees are feasible where necessary to cut off relatively thin layers of either natural levee or crevasse sands which lie immediately beneath the base of the levee and are in turn underlain by more impervious strata.

Relief Wells

Relief wells of proper spacing and penetration can be used to reduce excess hydrostatic pressure landward of levees underlain by a pervious foundation for a wide range of seepage entrances, foundation conditions, and landward top strata. The primary purpose of relief wells is to reduce artisan pressures above the ground surface which otherwise would cause formation of sand boils and possibly subsurface piping. Properly designed wells also reduce substratum pressures for a sufficient distance landward of the levee to preclude the possibility of dangerous seepage landward of the line of wells. Relief wells also intercept and provide controlled outlets for seepage which otherwise would emerge uncontrolled landward of the levee.

6 Program Limitations

While LEVSEEP is a very useful tool for design, certain limitations for use of the program should be noted. The solution algorithm is based on closed-form solutions that are based on several simplifying assumptions. These assumptions were discussed in Chapter 2 of this report. Based on the idealization of geometry required to formulate those equations, LEVSEEP should be used cautiously for problems involving uneven or irregular geometry. An alternative analysis method should be employed to verify results of such problems. This method may seem to be a problem related to the art of the individual engineer in idealizing the geometry and properties since LEVSEEP will provide the correct answer to the input problem; however, other methods of analysis can model irregular geometry and should be used for unusual conditions. Note that "piezometer" readings could be computed from alternative analysis and entered into LEVSEEP. LEVSEEP could then be used to compute costs, etc.

It is also assumed that the users of this program are experienced in levee design. This program requires considerable input from the user and contains many options that require knowledge of Corps procedures for levee design. *It is recommended that the user be familiar with the engineer publications referenced in Chapter 2 prior to use of LEVSEEP.*

LEVSEEP will not calculate the hydraulic gradient (I) for the case of no landside top blanket. The program does provide the total seepage quantity; however, to find the hydraulic gradient, the user must draw a flow net or perform some other method of analysis.

7 Summary, Conclusions, and Recommendations

Summary

The analysis software LEVSEEP provides a tool for the analysis of levee underseepage and rehabilitation. The analysis procedures employed by LEVSEEP are based on U.S. Army Corps of Engineer publications EM 1110-2-1913, EM 1110-2-1602, Engineer Bulletin 55-11, and TM 3-424 and thereby allow for similar analysis results. LEVSEEP should be used in accordance with Corps of Engineer publications referenced above. The models developed in those publications and incorporated into LEVSEEP make basic assumptions that must be recognized. Those assumptions are as follows:

a. Seepage may enter the pervious substratum at any point in the foreshore (usually at the riverside borrow pit) and/or through the riverside top stratum.

b. Flow through the top stratum is vertical.

c. Flow through the pervious foundation is horizontal.

d. The levee (including impervious or thick berms) and the portion of the top stratum beneath it are impervious.

e. All seepage is laminar.

The results obtained from LEVSEEP are consistent with those obtained from hand calculations following the aforementioned Corps publications. A thorough discussion of the comparison between LEVSEEP results and those from hand calculations can be found in Technical Report REMR-GT-13. LEVSEEP facilitates rapid analysis of levee underseepage for various geometrical configurations. LEVSEEP calculates seepage flow and substratum pressure based on geometry or piezometric data; plots cross sections and/or piezometer data; analyzes riverside blankets, landside berms, cutoffs, and relief wells; calculates the cost of construction of each control measure; and provides the user with a complete summary of all underseepage calculations,

control measure analyses, and control measure costs. This program provides the user with the necessary information for design and rehabilitation. This summary also allows the user to compare costs of the various control measures in order to select the most cost-effective control measure for a given levee section where rehabilitation is required. The graphics capabilities of LEVSEEP provide the user with a "picture" of the analysis while the plot capabilities allow the user to obtain a hard copy of this "picture." The full screen editing capabilities allow the user to change parameters easily and quickly reanalyze a section. Parameter studies that were extremely time-intensive utilizing hand computations can be performed in a fraction of the time using LEVSEEP.

This manual presents an overview of the operation of the computer program LEVSEEP and identifies the capabilities and limitations of the program. The computer program incorporates models for analyzing underseepage for levee profiles with various combinations of landside and riverside top stratums. Analysis models implemented in LEVSEEP were developed based on traditional analytical solutions. These traditional models were based on simplified geometries (uniform layer thicknesses) and uniform properties (permeability and specific weight). Irregular geometries and anisotropic soils provide limitations for analysis. LEVSEEP models a two-layer system with a top stratum and a pervious foundation material. For situations where no landside top stratum is present, LEVSEEP calculates the seepage quantity but is not capable of calculating the hydraulic gradient. The user is instructed to perform an alternative analysis (flow net analysis or other) to obtain the exit hydraulic gradient. For situations of a layered substratum, LEVSEEP calculates to obtain an equivalent transformed foundation and then proceeds to calculate the transformed two-layer problem. Key analysis parameters to be used as input for the program include geometry of the top blanket and pervious substratum foundation, landside and riverside pool elevations, levee toe elevations, landside and riverside blanket permeabilities, and foundation permeability. Profile geometry must be uniform. Blanket permeability must be constant. The residual head and hydraulic gradient are calculated at the landside toe of the levee except for the special case of no landside top stratum.

Several parameter studies were performed to demonstrate the program's capabilities. These studies included analysis of levee sections having various combinations of landside and riverside top blankets. The lengths of the riverside and landside blankets were varied, and the permeabilities of the blankets were varied. This parameter study of a prototype reach at Magnolia Levee, Huntington District, is described and included as an example in Appendix D. LEVSEEP results of various reaches have been compared with those of hand calculations. These comparisons included seepage calculations, control measure analyses, and control measure cost analyses. The results compared favorably and indicated the suitability of the developed model to predict underseepage behavior. The input and results of three of these reaches are included as example problems in Appendixes A through C.

Conclusions

Based on the results presented in this report, the following conclusions can be advanced:

a. The program is relatively simple and can be run on IBM compatible microcomputer running the MS DOS (TM) operating system having CGA or EGA graphics capabilities.

b. The analysis models are developed based on assumptions similar to those commonly followed in conventional analysis. Therefore, program solutions should allow the user to match conventional analyses.

c. Results from the implemented model seems to be reasonable. The two-layer model was verified using hand solutions for cases of uniform geometry where conventional solutions can be obtained. The model was verified for a three-layer foundation (example problem-cross6) by a comparison of the results of the LEVSEEP analysis of the transformed foundation to results from hand calculations. Good agreement was observed between results from the two analyses.

d. Results of control measure analysis compared well with results from hand calculations using Corps criteria.

e. Results of the case studies emphasized the importance of accurate characterization of the foundation sublayers. The length of the riverside and landside top blankets greatly impacts the predicted gradients.

f. LEVSEEP provides a convenient analysis tool that should allow designers to approximately model actual field conditions. Prediction of exit gradients and hydraulic heads for the case studies investigated reasonably matched measured data.

Flood protection is a complex process involving design, construction, maintenance, and performance evaluation of levees. The use of LEVSEEP can provide flexibility in exploring the influence of changing key parameters in the design process. The influence of these changing parameters on the predicted results can be analyzed. Such flexibility permits easy reevaluation of design criteria with the possible benefit of reducing cost and improving safety.

Recommendations

Based on the results of this research, the following recommendations are made:

a. The program LEVSEEP should be field tested by use in District offices, and the need for any corrections or improvements assessed.

b. LEVSEEP should be upgraded to incorporate recent changes in relief well analysis procedures as outlined in the U.S. Army Corps of Engineers "Design, Construction, and Maintenance of Relief Wells" (EM 1110-2-1914). It is also recommended that current entrance loss data for steel and plastic well screens be incorporated into the program.

c. To establish the limitations of LEVSEEP, finite element analyses allowing through seepage and assuming anisotropic conditions should be conducted. Finite element analyses can be used to establish the validity and limitations of transformed foundation analyses for multilayered substratum cases. Such analyses will provide information on the accuracy of the results from LEVSEEP, with the simplified assumptions, as compared to those obtained from more rigorous analyses. Finite element analyses can be conducted for cases where the top stratum and the substratum geometry have been idealized in order to assess the conservatism of current design methodology. With finite element analyses, limitations of LEVSEEP can be established with the use of variation of analysis geometry and key seepage parameters.

d. The output capabilities of LEVSEEP should be upgraded to provide adequate drawings for use in design at the District level.

e. The need for refining levee design criteria should be assessed. Many current criteria, such as dimensions and location of borrow pits and ditches, are arbitrary and conservative due to the lack of a rational analysis procedure.

Based on the conclusions stated above, LEVSEEP is recommended for widespread practical use by the U.S. Army Corps of Engineer Districts that analyze levee underseepage and rehabilitation. Analyses performed pursuant to U.S. Army Corps of Engineer publications EM 1110-2-1913, EM 1110-2-1602, Engineer Bulletin 55-11, and TM 3-424 can be obtained readily from LEVSEEP. LEVSEEP offers an excellent alternative to hand computations for levee underseepage, control measure analysis, and control measure cost analysis.

Corrections or improvements identified with regard to LEVSEEP should be forwarded to Mr. Hugh M. Taylor, Jr. at the U.S. Army Corps of Engineers Waterways Experiment Station, Soil and Rock Mechanics Division, Geotechnical Laboratory, Vicksburg, Mississippi, 39180.

References

Ashton-Tate. (1984). "DBASE II, version 2.41," Ashton-Tate, Culver City, CA.

Barron, R. A. (1947). "Relief wells for dams and levees," a discussion by Middlebrooks and Jervis, *Proceedings, American Society of Civil Engineers*, May 1947, pp 735-738.

__________. (1948). "The effect of a slightly pervious top blanket on the performance of relief wells," *Proceedings, 2nd International Conference on Soil Mechanics*, Rotterdam, Vol IV, p 324.

__________. (1984). "Mathematical analyses of landside seepage berms," Technical Report REMR-GT-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bathe, K. J. (1982). *Finite element procedures in engineering analysis*, Prentice-Hall, Inc., Englewood Cliffs, NJ.

Bennett, P. T. (1946). "The effect of blankets on the seepage through pervious foundation," *Transactions, American Society of Civil Engineers*, Vol 11, pp 215.

Conroy, P. (1984). "Computer program for relief well design according to TM 3-424," U.S. Army Engineer District, St. Louis, MO.

Cunny, R. W. (1980). "Documentation and analysis of Rock Island underseepage data," Technical Report GL-80-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Cunny, R. W., Agostinelli, V. M., Jr., and Taylor, H. M., Jr. (1989). "Levee underseepage software user manual and validation," Technical Report REMR-GT-13, U.S. Army Engineer Waterways Experiment Station, JAYCOR, Inc., Vicksburg, MS.

Cunny, R. W., Mlakar, P. F., and Agostinelli, V. M., Jr. (1985). "Development of a levee underseepage analysis program," Report No. J650-85-002/5370, JAYCOR, Structures Division, Vicksburg, MS.

Daniel, D. E. (1985). "Review of piezometric data for various ranges in the Rock Island District," report to U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Harr, M. E. (1962). *Ground and Seepage*, McGraw-Hill, New York, NY.

Headquarters, Department of the Army. (1955). "Relief well design," Civil Works Engineer Bulletin 55-11, Washington, DC.

_________. (1963). "Design of finite relief well systems, Engineer Manual 1110-2-1905, Washington, DC.

_________. (1978). "Engineering and design, design and construction of levees," Engineer Manual 1110-2-1913, Washington, DC.

_________. (1980). "Hydraulic design of reservoir outlet works," Engineer Manual 1110-2-1602, Washington, DC.

_________. (1986). "Seepage analysis and control for dams, Engineer Manual 1110-2-1901, Washington, DC.

_________. (1992). "Design, construction, and maintenance of relief wells," Engineer Manual 1110-2-1914, Washington, DC.

Microsoft Corporation. (1983). "Disk operating system, version 2.10," International Business Machines Corporation, Boca Raton, FL.

_________. (1984). "FORTRAN 77, version 3.20," International Business Machines Corporation, Boca Raton, FL.

_________. (1986). "QuickBASIC version 2.0," International Business Machines Corporation, Boca Raton, FL.

Middlebrooks, T. A., and Jervis, W. H. (1947). "Relief well systems for dams and levees," *Transactions, American Society of Civil Engineers*, Vol 112, p 1321.

Muskat, M. (1937). *The flow of homogenous fluids through pervious media.* McGraw-Hill, New York, NY.

Scanlon, J. M., Jr., McDonald, J. E., Jr., McAnear, C. L., Hart, E. D., Whalin, R. W., Williamson, G. R., and Mahloch, J. L. (1983). "Repair, evaluation, maintenance, and rehabilitation research program development report," U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Shockley, W. G., Cunny, R. W., Mlakar, P. F., Smith, W. G., Agostinelli, V. M., Jr. (1986). "Development of a levee underseepage analysis program to include design of relief wells, volume I: validation," Report No. J650-86-001/1372, JAYCOR, Structures Division, Vicksburg, MS.

Tracy, F. T. (1973). "A plane and axisymmetric finite element program for steady-state and transient seepage problems," Miscellaneous Paper K-73-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Turnbull, W. J., and Mansur, C. I. (1961a). "Investigation of underseepage - Mississippi River levees," *Transactions, American Society of Civil Engineers*, Vol 126, pp 1486-1539.

__________. (1961b). "Design of control measures for dams and levees," *Transactions, American Society of Civil Engineers*, Vol 126, pp 1540-1568.

U.S. Army Engineer District, St. Louis. (1976). "Re-evaluation of underseepage controls, Mississippi River levees, Alton to Gale, Illinois," report to Lower Mississippi Valley Division.

U.S. Army Engineer Division, Huntsville. (1986). "Corps of Engineers training course, seepage analysis and control for dams," prepared for U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

U.S. Army Engineer Waterways Experiment Station. (1956). "Investigation of underseepage and its control, lower Mississippi River levees, volume I," Technical Memorandum 3-424, prepared for Mississippi River Commission, Vicksburg, MS.

__________. (1973). "Computer program H2030-discharge in pressure conduits using the Darcy-Weisbach formula," Vicksburg, MS.

__________. (1979). "Graphics compatibility system (GCS) programmer's reference manual," Automatic Data Processing Center, Vicksburg, MS.

Wolff, T. F. (1974). "Performance of underseepage control measures during the 1973 Mississippi River flood, Columbia Levee District, Illinois," Master Thesis, Oklahoma State University.

__________. (1986). "Design and performance of underseepage controls: a critical review," research report prepared for the U.S. Army Engineer Waterways Experiment Station, Michigan State University, East Lansing, MI.

Wolff, T. F. (1987). "Levee underseepage analysis for special foundation conditions," research report prepared for the U.S. Army Engineer Waterways Experiment Station, Michigan State University, East Lansing, MI.

__________. (1989). "LEVEEMSU: a software package designed for levee underseepage analysis" Technical Report GL-89-13, prepared for the U.S. Army Engineer Waterways Experiment Station, Michigan State University, East Lansing, MI.

Wolff, T. F., and Taylor, H. M. (1991). "Critical review of levee underseepage," technical report prepared for the U.S. Army Engineer Waterways Experiment Station, Michigan State University, East Lansing, MI.

Appendix A: Example Problem from Keyboard Input (Cross Section 5 - Stovall, Mississippi)

This appendix consists of an example problem to be input from the keyboard. The input for this problem is presented along with the output generated by LEVSEEP. The problem analyzes initial conditions and the various control measures available. The graphics generated from these analyses are also included with this example problem. This example problem represents a levee section from Stovall, Mississippi, namely sta 77/38+00. The user may input the data shown to observe how the program works.

CROSS SECTION DATA INPUT SCREEN

LINE#	X	Y	lINE#	X	Y	LINE#	X	Y
1	-1600	164.5	1	110	170	1	1201	164.5
1	-400	164.5	1	190	167.5	1	1600	164.5
1	-390	168	1	200	164.5	2	-800	153
1	-125	178	1	400	164.5	2	200	153
1	-10	201.3	1	401	155	2	201	151
1	10	201.3	1	1200	157	2	400	151

POINT NUMBER : 1
SCREEN 1 OF 2

<Esc> exit screen
<^PgUp> previous screen
<^PgDn> next screen

CROSS SECTION DATA INPUT SCREEN

LINE#	X	Y	lINE#	X	Y	LINE#	X	Y
2	401	157	5	-1600	113			
3	1200	157	5	1600	113			
3	1201	151						
3	1600	151						
4	-800	164.5						
4	-800	113						

POINT NUMBER : 19
SCREEN 2 OF 2

<Esc> exit screen
<^PgUp> previous screen
<^PgDn> next screen

Figure A1. Levee underseepage analysis cross section input

```
GEOTECHNICAL DATA INPUT/EDIT SCREEN

PROJECT NAME   STOVALL, MISSISSIPPI

STATION #  77/38+00        LANDSIDE TOE ELEV   164.5

LANDSIDE TOE OFFSET  400             RIVERSIDE TOE OFFSET   200

NET HEAD ON LEVEE  29.8            RIVERWARD EXTENT OF TOP STRATUM  200

LANDWARD EXTENT OF TOP STRATUM  400            ENTRANCE  open

EXIT  blocked          SUBMERGED WEIGHT   50


NUMBER OF LAYERS COMPOSING PERVIOUS FOUNDATION   1

NUMBER OF LAYERS COMPOSING LANDSIDE STRATA    1

NUMBER OF LAYERS COMPOSING RIVERSIDE STRATA    1
                                              <Esc> exit screen
```

```
SUBSTRATUM PERMEABILITY DATA (AVERAGED)

COEFFICENT OF PERMEABILITY                         .25

EFFECTIVE THICKNESS OF PERVIOUS SUBSTRATUM         40

ACTUAL DEPTH OF PERVIOUS SUBSTRATUM                40







                                              <Esc> exit screen
```

Figure A2.   Levee underseepage analysis geotechnical properties input (Continued)

LANDSIDE AND RIVERSIDE PERMEABILITY DATA (AVERAGED)	
EFFECTIVE THICKNESS OF LANDSIDE TOP STRATUM	11.5
PERMEABILITY OF LANDSIDE TOP STRATUM	.00015
EFFECTIVE THICKNESS OF RIVERSIDE TOP STRATUM	13.5
PERMEABILITY OF RIVERSIDE TOP STRATUM	.00002
EFFECTIVE THICKENESS FOR UPLIFT	11.5
TOP STRATUM THICKNESS	14

<Esc> exit screen

Figure A2. (Concluded)

INPUT PIEZOMETER LOCATIONS OR READINGS

LOCATIONS (L)   READINGS (R)

PIEZOMETER DATA INPUT SCREEN / LOCATIONS

POINT NUMBER	PIZO STATION	PIZO OFFSET	TIP ELEV	TOP ELEV
B-3	38+00	20u/s	140	200
B-4	38+00	200d/s	145	175
B-5	38+00	400d/s	140	165
B-6	38+00	600d/s	135	165
B-7	38+00	985d/s	130	165

POINT NUMBER : 1
SCREEN 1 OF 1

<Esc> exit screen
<^PgUp> previous screen
<^PgDn> next screen

PIEZOMETER DATA INPUT SCREEN

POINT NUMBER	DATE OF READING	PIZO READING	POOL READING
B-3	05/09/1973	175.3	178.2
B-4	05/09/1973	174.1	178.2
B-5	05/09/1973	172.4	178.2
B-6	05/09/1973	167.3	178.2
B-7	05/09/1973	172.5	178.2

POINT NUMBER : 1
SCREEN 1 OF 1

<Esc> exit screen
<^PgUp> previous screen
<^PgDn> next screen

Figure A3. Levee underseepage analysis piezometer data input

```
BERM CONTROL MEASURE INPUT

FACTOR OF SAFETY FOR BERM
                                 INPUT HERE WILL CAUSE PROGRAM TO CALCULATE
                                 LEVEE LANDSIDE TOE ALL. UPWARD GRADIENT

LEVEE LANDSIDE TOE ALLOWABLE UPWARD GRADIENT  .3

BERM LANDSIDE TOE ALLOWABLE UPWARD GRADIENT  .8

LANDSIDE SLOPE OF LEVEE  .076

SLOPE AT BERM TOE  .25

                                                  <Esc> exit screen
```

```
RIVERSIDE BLANKET CONTROL INPUT

BLANKET LANDSIDE TOE ALLOWABLE UPWARD GRADIENT .7

SLOPE AT TRIANGULAR RIVERSIDE BLANKET TOE  .25

RIVERSIDE LEVEE AVERAGE SLOPE .19

                                                  <Esc> exit screen
```

Figure A4. Levee underseepage analysis control measure and unit cost input (Sheet 1 of 4)

```
RELIEF WELL CONTROL INPUT

SAFETY FACTOR FOR WELL                        INPUT HERE WILL CAUSE PROGRAM TO CALC
                                              LEVEE LANDSIDE TOE ALL. UPWARD GRADIENT

LEVEE LANDSIDE TOE ALLOWABLE UPWARD GRADIENT  .53

EFFECTIVE WELL RADIUS 1

INSIDE WELL PIPE DIAMETER  .67

COEFFICIENT OF PIPE ROUGHNESS  .0001
                               stainless steel .... 0.00005
                               galvanized steel ... 0.0006
                               plastic, pvc ....... 0.0001

VISCOSITY OF WATER  .0000121

% REDUCTION OF SEEPAGE FLOW BENEATH LEVEE  1

WELL TOP HEIGHT  .33                                <Esc> exit screen
```

```
BERM UNIT COST INPUT

UNSPECIFIED BERM      1.3

IMPERVIOUS BERM       1.3

SEMIPERVIOUS BERM     1.3

SAND BERM             3.75

PERVIOUS BERM WITH A COLLECTOR PIPE  3.75

ROCK ISLAND BERM      3.75



                                                    <Esc> exit screen
```

Figure A4. (Sheet 2 of 4)

CUTOFF COST MENU

USE DEFAULTS yes

$ 3.00 ABOVE 65 FEET

$ 8.00 BELOW 65 FEET

<Esc> exit screen

RIVERSIDE BLANKET UNIT COST INPUT

BLANKET UNIT COST 1.2

<Esc> exit screen

Figure A4. (Sheet 3 of 4)

RELIEF WELL UNIT COST INPUT

DRILLING THROUGH TOP STRATUM	20	
DRILLING THROUGH FOUNDATION	16	
RISER PIPE	30	stainless steel .... 80.00 galvanized steel ... 40.00 plastic, pvc 30.00
WELL SCREEN	85	stainless steel .... 125.00 galvanized steel ... 75.00 plastic, pvc 85.00
FILTER	12	
BACKFILLING	400	
WELL COVER	300	
WELL DEVELOPMENT AND TEST	1000	<Esc> exit screen

Figure A4. (Sheet 4 of 4)

```
PROJECT NAME : STOVALL, MISSISSIPPI
STATION      : 77/38+00

                        INITIAL CONDITIONS
                        ------------------

X1 =   199.61 FT
X3 =  2048.18 FT
M  =  0.0105
I  =  1.8637
Qs =    154.20 GPM/100 FT

HO    =   21.43 FT
$     =  0.0140460
?
```

Figure A5. Levee underseepage analysis initial conditions calculation

```
BERM (B)
RIVERSIDE BLANKET (R)
CUTOFF (C)
WELL (W)
```

```
          BERM SELECTION MENU

1. IMPERVIOUS BERM
2. SEMIPERVIOUS BERM
3. PERVIOUS BERM WITH COLLECTOR PIPE
4. SAND BERM
5. ROCK ISLAND BERM

ENTER NUMBER OF CHOICE ===>
? 1


 PROJECT : STOVALL, MISSISSIPPI
 STATION : 77/38+00
                 OUTPUT DATA FOR BERM ANALYSIS
                 -----------------------------

IMPERVIOUS BERM
 X1 =    199.61 FT
 X3 = UNDEFINED
 M  = UNDEFINED
 I  = UNDEFINED
 Qs = UNDEFINED

 XI =    400.00 FT
 T  =     12.13 FT
 VB =     15726.09 CU YD/100 FT
?


              BERM COST CALCULATION
              ---------------------

IMPERVIOUS BERM
 VB          =    15726.09 CU YD/100 FT
 UNIT COST  = $       1.30 /CU YD
 TOTAL COST = $   20443.91 /100 FT LEVEE STATION
?
```

Figure A6. Control measure calculations berm analysis (Sheet 1 of 4)

```
                BERM SELECTION MENU

     1. IMPERVIOUS BERM
     2. SEMIPERVIOUS BERM
     3. PERVIOUS BERM WITH COLLECTOR PIPE
     4. SAND BERM
     5. ROCK ISLAND BERM

     ENTER NUMBER OF CHOICE ===>
    ? 2




      PROJECT : STOVALL, MISSISSIPPI
      STATION : 77/38+00

                     OUTPUT DATA FOR BERM ANALYSIS
                     -----------------------------

     SEMIPERVIOUS BERM
      X1 =    199.61 FT
      X3 = UNDEFINED
      M  = UNDEFINED
      I  = UNDEFINED
      Qs = UNDEFINED

      XSP=    400.00 FT
      T  =     12.13 FT
      VB =     15726.09 CU YD/100 FT
     ?



                 BERM COST CALCULATION
                 ---------------------

     SEMIPERVIOUS BERM
      VB         =     15726.09 CU YD/100 FT
      UNIT COST  = $         1.30 /CU YD
      TOTAL COST = $    20443.91 /100 FT LEVEE STATION
     ?
```

Figure A6. (Sheet 2 of 4)

```
             BERM SELECTION MENU

 1. IMPERVIOUS BERM
 2. SEMIPERVIOUS BERM
 3. PERVIOUS BERM WITH COLLECTOR PIPE
 4. SAND BERM
 5. ROCK ISLAND BERM

 ENTER NUMBER OF CHOICE ===>
? 3



  PROJECT : STOVALL, MISSISSIPPI
  STATION : 77/38+00
                    OUTPUT DATA FOR BERM ANALYSIS
                    -----------------------------

PERVIOUS BERM WITH COLLECTOR PIPE
 X1 =    199.61 FT
 X3 = UNDEFINED
 M  = UNDEFINED
 I  = UNDEFINED
 Qs = UNDEFINED

 XP =    400.00 FT
 T  =     12.13 FT
 VB =     15726.09 CU YD/100 FT
?



               BERM COST CALCULATION
               ---------------------

PERVIOUS BERM WITH COLLECTOR PIPE
 VB           =     15726.09 CU YD/100 FT
 UNIT COST    = $        3.75 /CU YD
 TOTAL COST   = $    58972.82 /100 FT LEVEE STATION
?
```

Figure A6. (Sheet 3 of 4)

```
              BERM SELECTION MENU

  1. IMPERVIOUS BERM
  2. SEMIPERVIOUS BERM
  3. PERVIOUS BERM WITH COLLECTOR PIPE
  4. SAND BERM
  5. ROCK ISLAND BERM

 ENTER NUMBER OF CHOICE ===>
? 4




  PROJECT : STOVALL, MISSISSIPPI
  STATION : 77/38+00

                    OUTPUT DATA FOR BERM ANALYSIS
                    -----------------------------

 SAND BERM
  X1 =    199.61 FT
  X3 = UNDEFINED
  M  = UNDEFINED
  I  = UNDEFINED
  Qs = UNDEFINED

  XS =    400.00 FT
  T  =     12.13 FT
  VB =     15726.09 CU YD/100 FT
 ?




              BERM COST CALCULATION
              ---------------------

 SAND BERM
  VB          =     15726.09 CU YD/100 FT
  UNIT COST   = $        3.75 /CU YD
  TOTAL COST  = $    58972.82 /100 FT LEVEE STATION
 ?
```

Figure A6. (Sheet 4 of 4)

```
                    CUTOFF ANALYSIS
                    ---------------

 DC/D : CUTOFF DEPTH/DEPTH RATIO ===>
? .95



 PROJECT : STOVALL, MISSISSIPPI
 STATION : 77/38+00
               OUTPUT DATA FOR CUTOFF ANALYSIS
               -------------------------------


  DC/D = .95

  X1 =    199.61 FT
  X3 =   2048.18 FT
  M  =   0.0106
  I  =   1.7995
  Qs =     145.82 GPM/100 FT
 ?



               CUTOFF COST CALCULATION
               -----------------------

  DEPTH =    52.00
  COST  = $    15600.00 /100 FT OF LEVEE STATION
 ?
```

Figure A7. Control measure calculations cutoff analysis

```
STATION : 77/38+00

      OUTPUT DATA FOR RELIEF WELL ANALYSIS
      ------------------------------------

X1 =   199.61 FT
X3 =  2048.18 FT
M  = UNDEFINED
I  = UNDEFINED
Qs =     154.03 GPM/100 FT
J  =  0  %
```

P ft	ASEL ft	WBAR ft	QW gal/100 ft	COST $
0.25	94.90	10.00	370.26	3719.86
0.38	125.86	15.00	469.62	3253.71
0.50	149.86	20.00	599.83	3109.57
0.63	168.42	25.00	665.85	3102.43
0.75	182.73	30.00	708.29	3168.63
0.88	193.89	35.00	771.33	3277.65
1.00	202.68	40.00	782.30	3414.31
0.63	168.42	25.00	665.85	3102.43

?

Figure A8. Control measure calculations relief well analysis

```
                    BLANKET ANALYSIS
                    ----------------

 IS THERE A BORROW PIT? (Y/N)
? Y



           RIVERSIDE BLANKET ANALYSIS
           --------------------------

 XR =  4733.90
 L1 =   200.00

IF XR OR LB > DISTANCE TO RIVER, SOLUTION INFEASIBLE

 DO YOU WANT TO CONTINUE? (Y/N)
? Y

 ZBR : TOP STRATUM THICKNESS IN BORROW PIT ===>
? 0



                 INPUT CHOICES
                 -------------

1. LB,KB
2. LB,ZB
3. KB,ZB

 ENTER NUMBER OF CHOICE ===>
? 1

 LB : BLANKET WIDTH (DEFAULT=BORROW PIT WIDTH) ===>
? 800
```

Figure A9. Control measure calculations blanket analysis (Continued)

```
              DETERMINE KB AND ZB
              -------------------

ENTER VALUE OF KB ...  ZB IS CALCULATED
WHEN FINISHED, HIT RETURN TO CHOOSE VALUE

        KB (CM/S)            ZB (FT)
        ---------            -------

?
 ENTER VALUE OF KB TO USE ===>
? .1E-04




 PROJECT : STOVALL, MISSISSIPPI
 STATION : 77/38+00
                OUTPUT DATA FOR BLANKET ANALYSIS
                --------------------------------

X1 =  4718.33 FT
X3 =  2048.18 FT
M  =  0.0039
I  =  0.7014
Qs =     58.03 GPM/100 FT

XR  =  4733.90 FT
LB  =   800.00 FT
KB  =  0.00001000 CM/SEC
ZB  =     3.56 FT
VRB =    10559.53 CU YD/100 FT
?




              BLANKET COST CALCULATION
              ------------------------

VRB         =     10559.53 CU YD/100 FT
UNIT COST   = $        1.20 /CU YD
TOTAL COST  = $    12671.44 /100 FT OF LEVEE STATION
?
```

Figure A9. (Concluded)

```
PROJECT NAME : STOVALL, MISSISSIPPI
STATION      : 77/38+00

             FROM PIEZOMETER DATA
             --------------------

X1 =   351.67 FT
X3 =  1560.01 FT
M  =  0.0055
I  =  0.7399
Qs =      80.38 GPM/100 FT

H  =     13.70 FT
l1 =    420.00 FT
h1 =     10.80 FT
l2 =    200.00 FT
h2 =      9.60 FT
H0 =      8.51 FT
S  =    951.67 FT
?
```

Figure A10. Levee underseepage analysis from piezometer data

```
    PROJECT NAME : STOVALL, MISSISSIPPI
    STATION      : 77/38+00

                                INITIAL CONDITIONS
                                ------------------
                              X1 =   199.61 FT
                              X3 =  2048.18 FT
                              M  =  0.0105
                              I  =  1.8637
                              Qs =  154.20 GPM/100 FT

                              H0   =   21.43 FT
                              $    =  0.0140

           OUTPUT DATA FOR BERM ANALYSIS
           -----------------------------
   IMPERVIOUS BERM                 PERVIOUS BERM

    X1 =    199.61 FT               X1 =    199.61 FT
    X3 = UNDEFINED                  X3 = UNDEFINED
    M  = UNDEFINED                  M  = UNDEFINED
    I  = UNDEFINED                  I  = UNDEFINED
    Qs = UNDEFINED                  Qs = UNDEFINED

    X  =    400.00 FT               X  =    400.00 FT
    T  =     12.13 FT               T  =     12.13 FT

   SEMIPERVIOUS BERM               SAND BERM

    X1 =    199.61 FT               X1 =    199.61 FT
    X3 = UNDEFINED                  X3 = UNDEFINED
    M  = UNDEFINED                  M  = UNDEFINED
    I  = UNDEFINED                  I  = UNDEFINED
    Qs = UNDEFINED                  Qs = UNDEFINED

    X  =    400.00 FT               X  =    400.00 FT
    T  =     12.13 FT               T  =     12.13 FT
```

Figure A11. Levee underseepage analysis summary of calculations (Sheet 1 of 3)

OUTPUT DATA FOR BLANKET ANALYSIS

```
X1 =  4718.33 FT
X3 =  2048.18 FT
M  =  0.0039
I  =  0.7014
Qs =    58.03 GPM/100 FT

XR  =  4733.90 FT
LB  =   800.00 FT
KB  =  0.0000
ZB  =      3.56 FT
```

OUTPUT DATA FOR CUTOFF ANALYSIS

```
X1 =   199.61 FT
X3 =  2048.18 FT
M  =  0.0106
I  =  1.7995
Qs =  145.82 GPM/100 FT

DC/D = .95
```

OUTPUT DATA FOR RELIEF WELL ANALYSIS

```
X1 =   199.61 FT
X3 =  2048.18 FT
M  = UNDEFINED
I  = UNDEFINED
Qs =  154.03 GPM/100 FT
J  =  0  %
```

P ft	ASEL ft	WBAR ft	QW gal/100 ft	COST $
0.25	94.90	10.00	370.26	3719.86
0.38	125.86	15.00	469.62	3253.71
0.50	149.86	20.00	599.83	3109.57
0.63	168.42	25.00	665.85	3102.43
0.75	182.73	30.00	708.29	3168.63
0.88	193.89	35.00	771.33	3277.65
1.00	202.68	40.00	782.30	3414.31
0.63	168.42	25.00	665.85	3102.43

Figure A11. (Sheet 2 of 3)

COST SUMMARY FOR ALL CONTROL MEASURES

TYPE	VOLUME CU YD/100 FT	UNIT COST $	TOTAL $
IMPERVIOUS BERM	15726.09	1.30	20443.91
SEMIPERVIOUS BERM	15726.09	1.30	20443.91
PERVIOUS BERM	15726.09	3.75	58972.82
SAND BERM	15726.09	3.75	58972.82
RIVERSIDE BLANKET	12671.44	1.20	10559.53

CUTOFF

DC/D = .95
DEPTH = 52.00 FT
TOTAL = 15600.00 $

RELIEF WELL - LOWEST COST

DEPTH = 25.00 FT
SPACING = 168.42 FT
TOTAL = 3102.43 $

Figure A11. (Sheet 3 of 3)

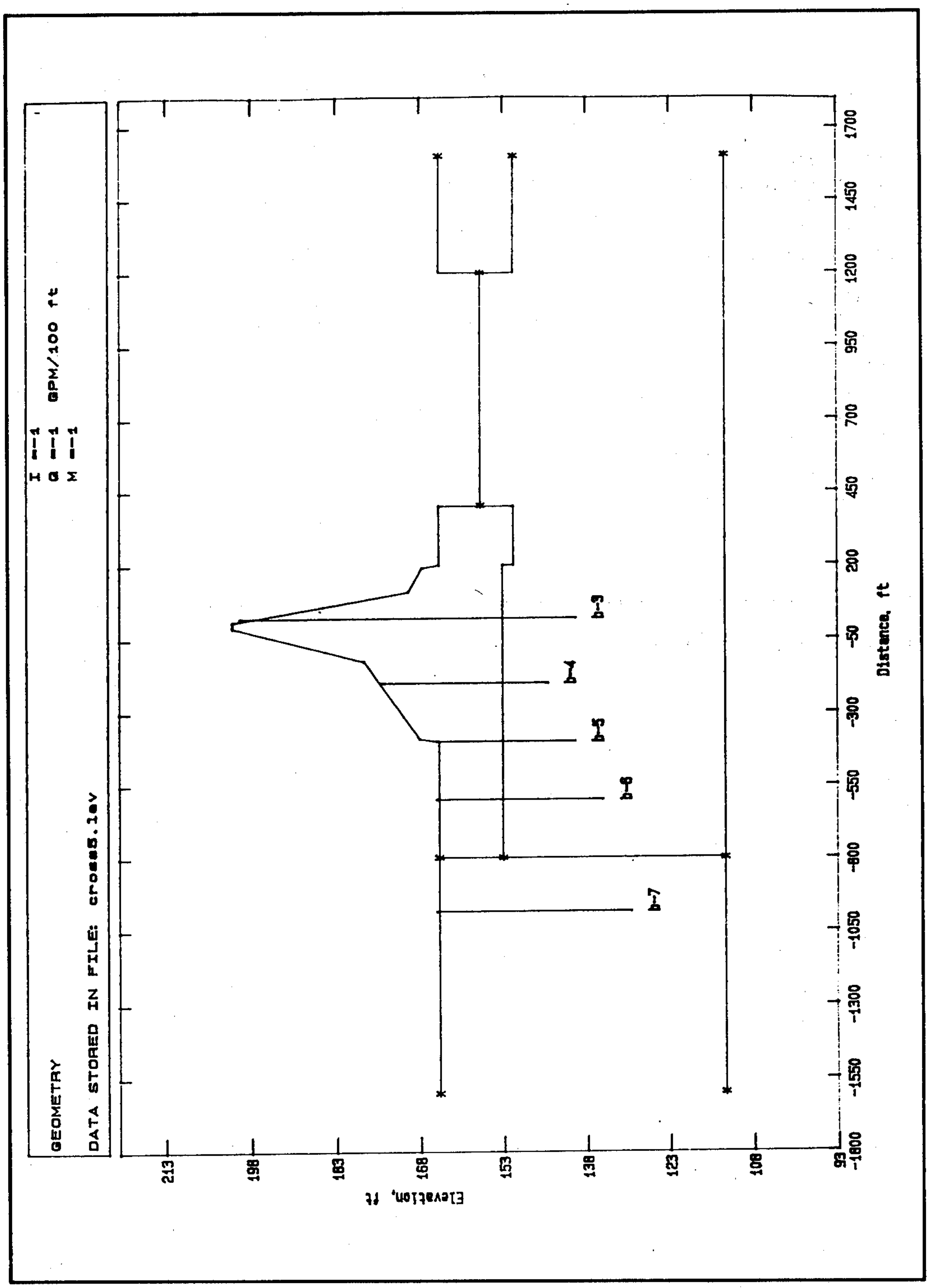


Figure A12. Geometry

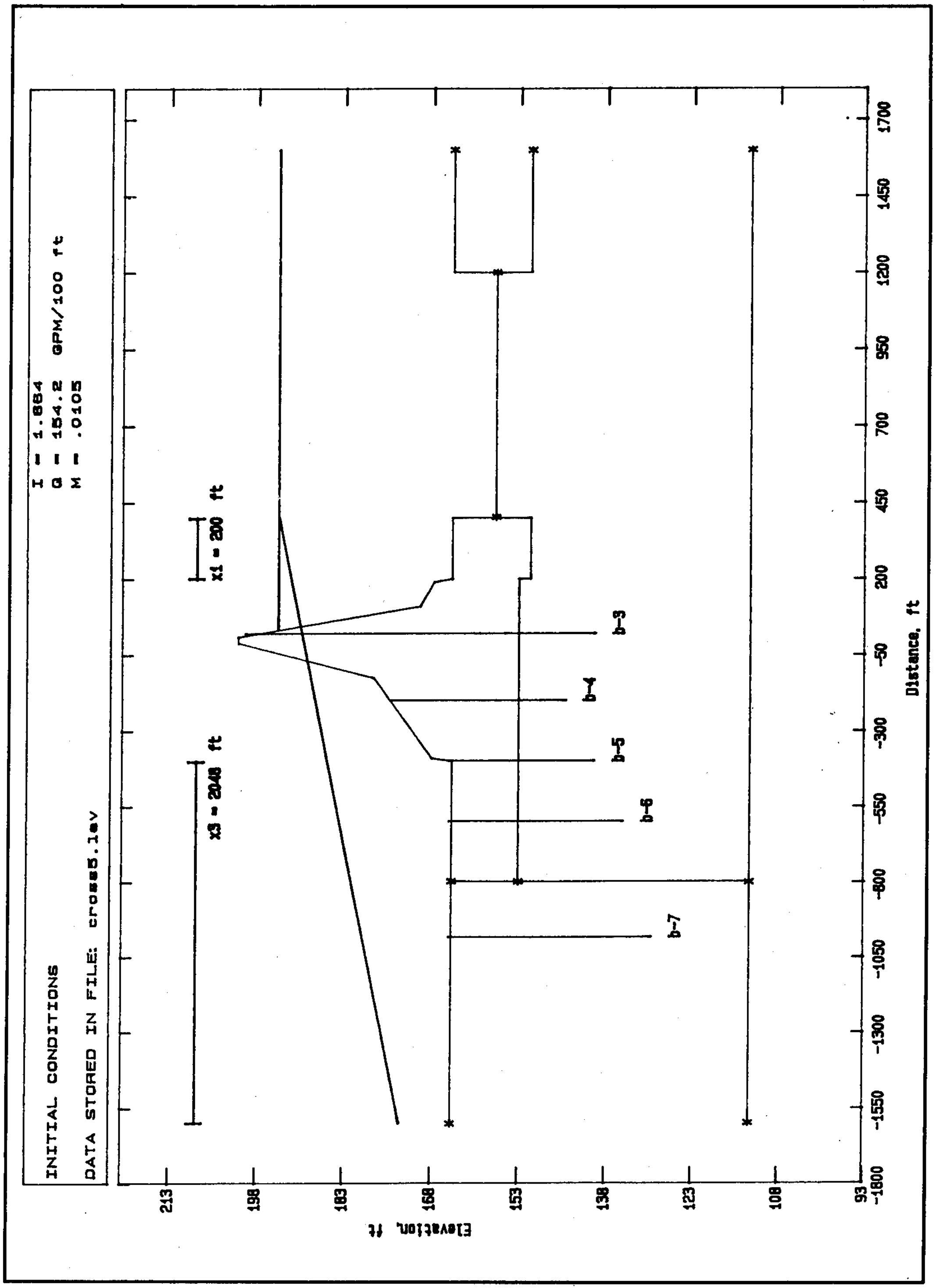


Figure A13. Initial conditions

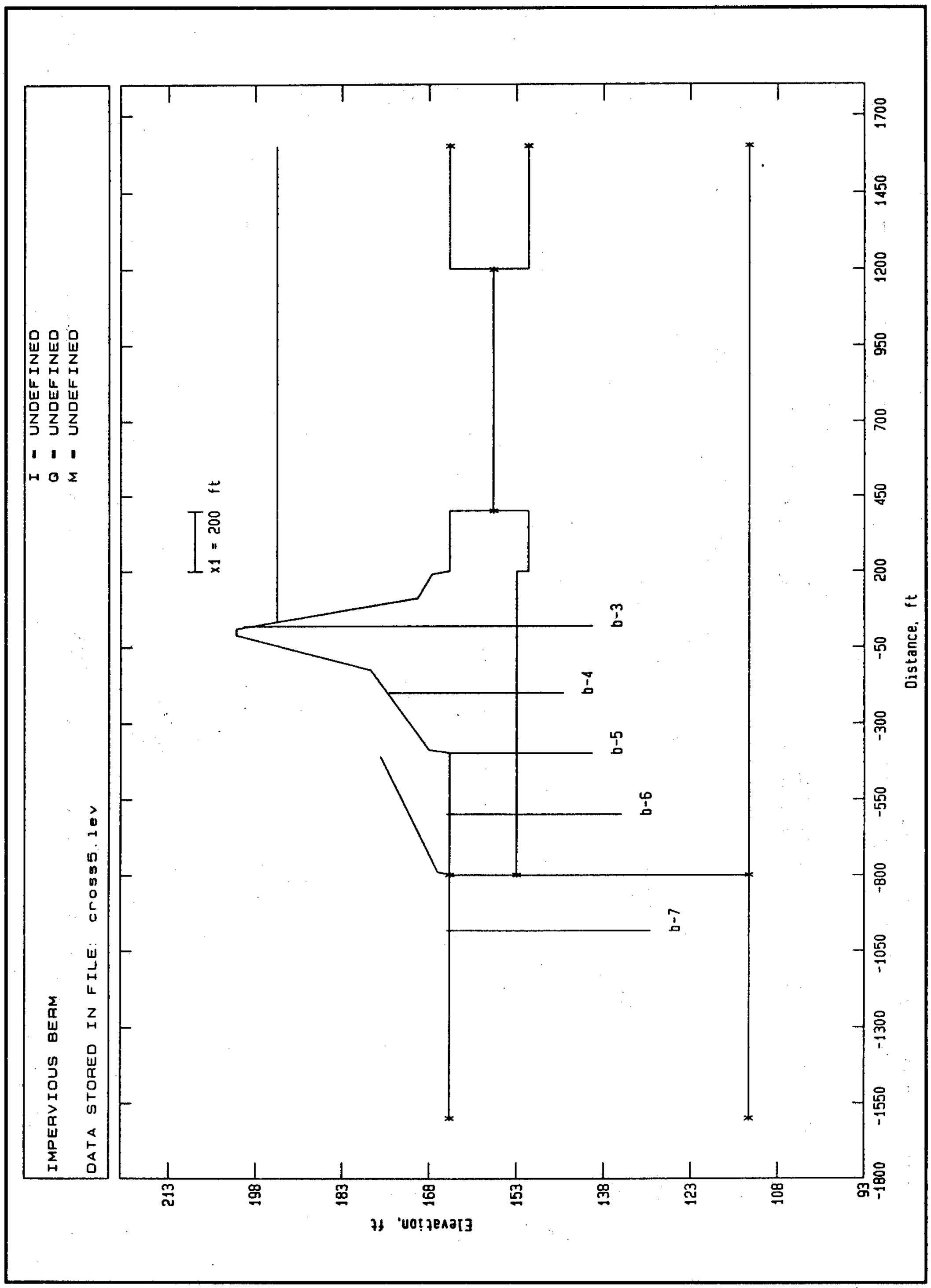


Figure A14. Impervious berm

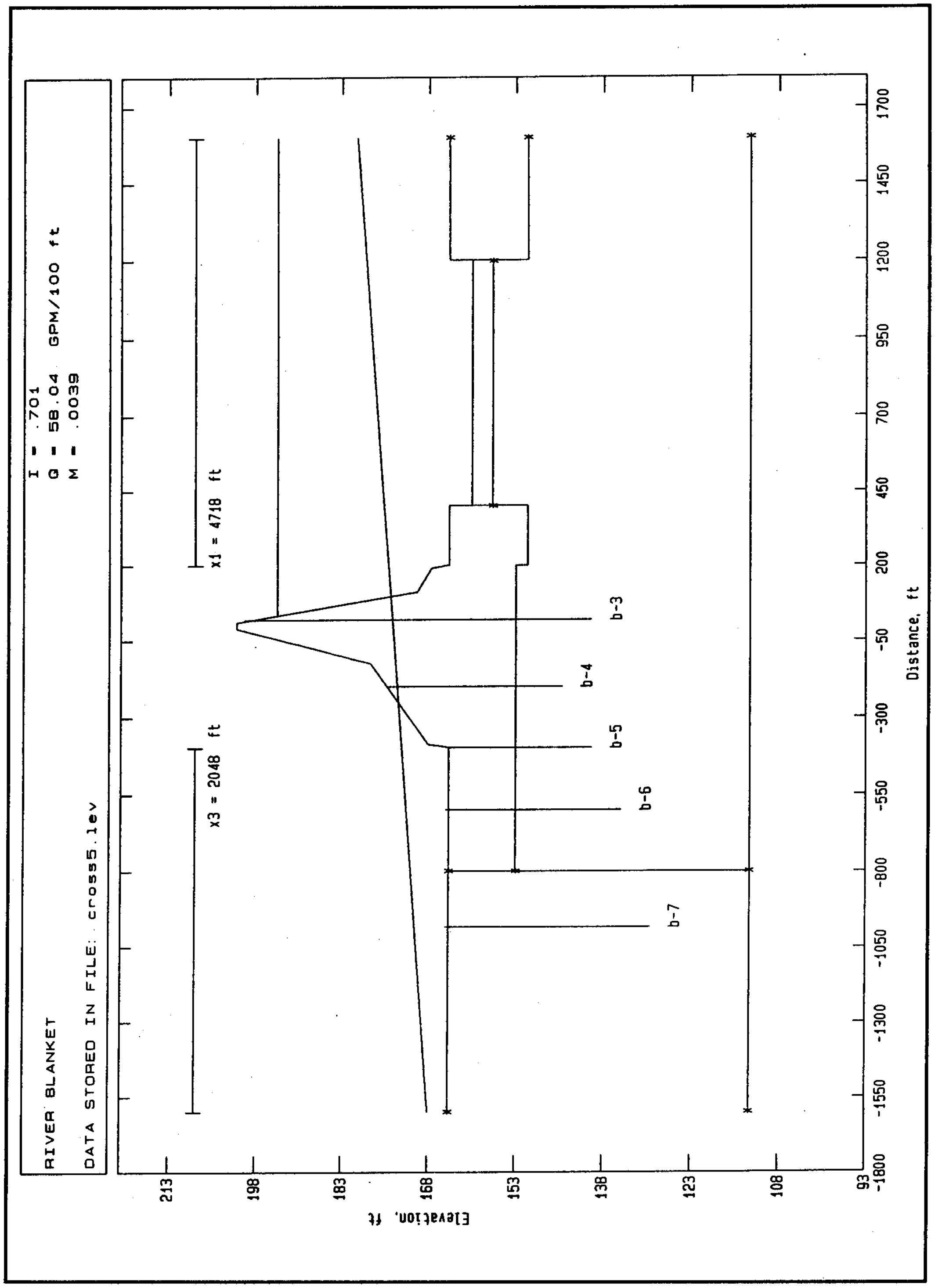


Figure A15. River blanket

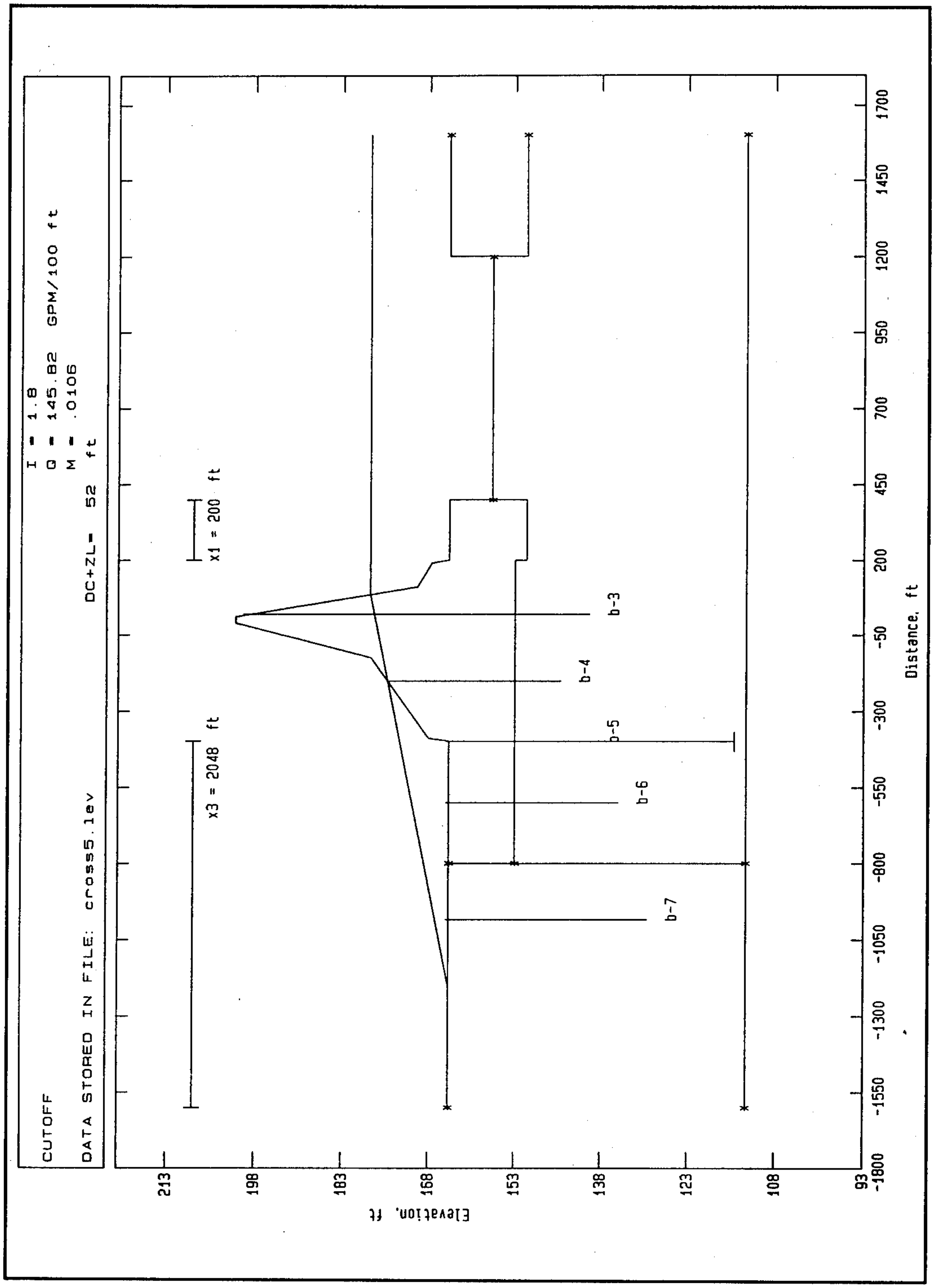


Figure A16. Cutoff

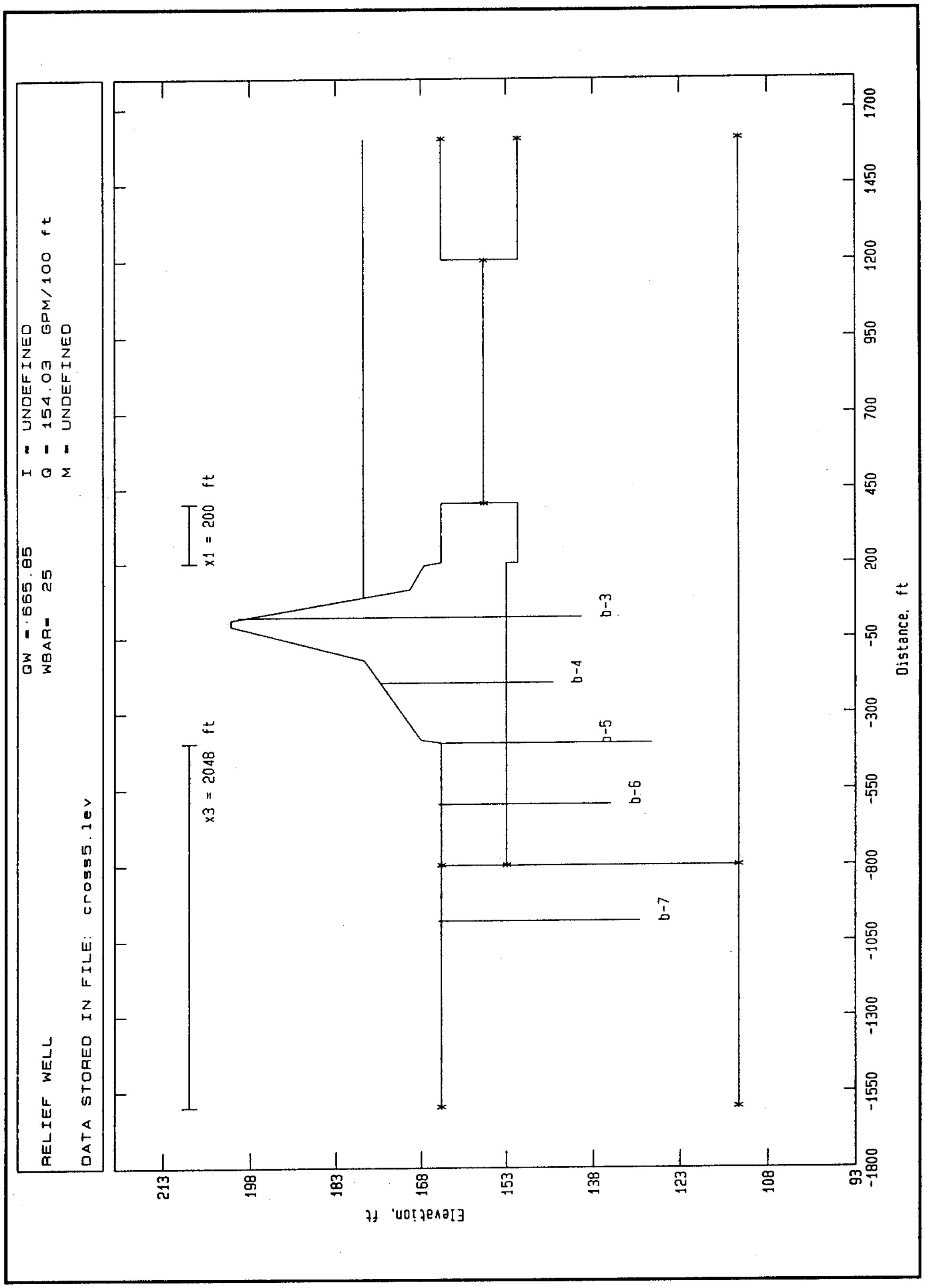


Figure A17. Relief well

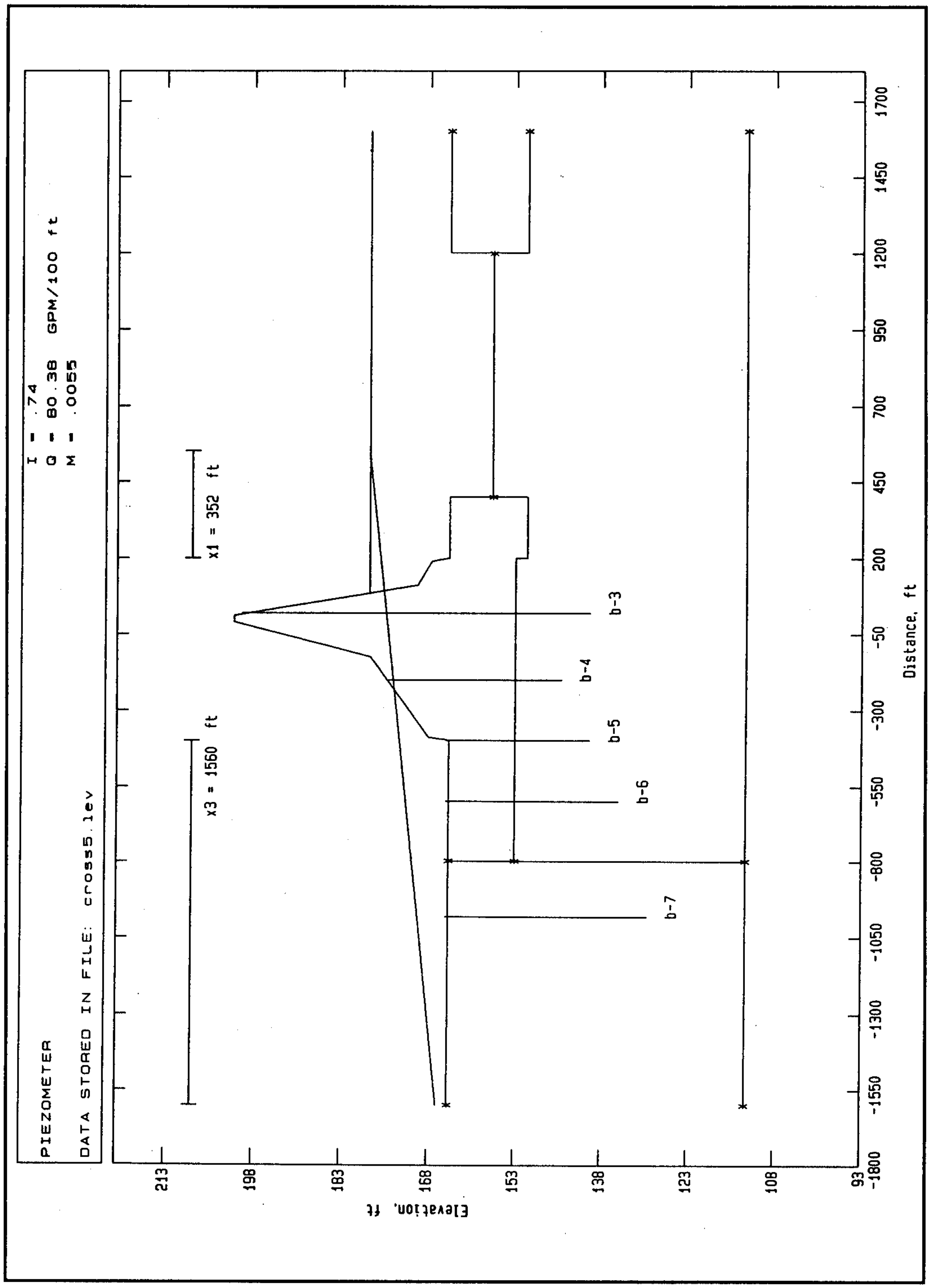


Figure A18. Piezometer

Appendix B: Example Problem from File (Cross Section 6 - Well Analysis for Three-layer Foundation with Top Strata and Open Entrance and Exit Conditions)

This appendix consists of an example to be accessed as an existing file. The input file, calculations, and summary are presented in this appendix. This example problem calculates the initial conditions and an analysis for relief wells. The analyses are performed for the case of a three-layer foundation with top strata and open entrance and exit conditions. The three-layer foundation is transformed to an equivalent uniform layer and then evaluated. To access the file, the user should start the program by typing LEVSEEP followed by the <enter> command. The program will initialize, and the main menu will appear. Under the INPUT/EDIT DATA from FILE menu heading is the Load File command. The user should type "L" and <enter> and then enter the file name "cross6" when prompted. The user may access and view the input data under the INPUT/EDIT from Keyboard options.

CROSS SECTION DATA INPUT SCREEN

LINE#	X	Y	LINE#	X	Y	LINE#	X	Y
1	-510	106	1	1200	100	4	1200	75
1		106	2	-510	100	5	-510	
1	100	139	2	1200	100	5	1200	
1	120	139	3	-510	90	6		106
1	220	106	3	1200	90	6		100
1	1200	106	4	-510	75	7	220	106

POINT NUMBER : 1
SCREEN 1 OF 2

<Esc> exit screen
<^PgUp> previous screen
<^PgDn> next screen

CROSS SECTION DATA INPUT SCREEN

LINE#	X	Y	LINE#	X	Y	LINE#	X	Y
7	220	100						

POINT NUMBER : 19
SCREEN 2 OF 2

<Esc> exit screen
<^PgUp> previous screen
<^PgDn> next screen

Figure B1. Levee underseepage analysis cross-section input

GEOTECHNICAL DATA INPUT/EDIT SCREEN

PROJECT NAME EXAMPLE OF 3 LAYER FOUNDATION

STATION # CROSS 6 LANDSIDE TOE ELEV 106

LANDSIDE TOE OFFSET 100 RIVERSIDE TOE OFFSET 120

NET HEAD ON LEVEE 30 RIVERWARD EXTENT OF TOP STRATUM 980

LANDWARD EXTENT OF TOP STRATUM infinite ENTRANCE open

EXIT infinite SUBMERGED WEIGHT 50

NUMBER OF LAYERS COMPOSING PERVIOUS FOUNDATION 3

NUMBER OF LAYERS COMPOSING LANDSIDE STRATA 1

NUMBER OF LAYERS COMPOSING RIVERSIDE STRATA 1

<Esc> exit screen

SUBSTRATUM PERMEABILITY DATA (LAYERED)

THICK -NESS	PERMEABILITY HORZ	VERT	THICK -NESS	PERMEABILITY HORZ	VERT	THICK -NESS	PERMEABILITY HORZ	VERT
10	.0125	.005						
15	.02	.01						
75	.12	.06						

POINT NUMBER : 1
SCREEN 1 OF 1

<Esc> exit screen
<^PgUp> previous screen
<^PgDn> next screen

Figure B2. Levee underseepage analysis geotechnical properties input (Continued)

LANDSIDE AND RIVERSIDE PERMEABILITY DATA (AVERAGED)

EFFECTIVE THICKNESS OF LANDSIDE TOP STRATUM	6
PERMEABILITY OF LANDSIDE TOP STRATUM	.0003
EFFECTIVE THICKNESS OF RIVERSIDE TOP STRATUM	6
PERMEABILITY OF RIVERSIDE TOP STRATUM	.0003
EFFECTIVE THICKNESS FOR UPLIFT	6
TOP STRATUM THICKNESS	6

<Esc> exit screen

Figure B2. (Concluded)

```
RELIEF WELL CONTROL INPUT

SAFETY FACTOR FOR WELL                     INPUT HERE WILL CAUSE PROGRAM TO CALC
                                           LEVEE LANDSIDE TOE ALL. UPWARD GRADIENT

LEVEE LANDSIDE TOE ALLOWABLE UPWARD GRADIENT  .534

EFFECTIVE WELL RADIUS 1

INSIDE WELL PIPE DIAMETER  .67

COEFFICIENT OF PIPE ROUGHNESS  .0001
                               stainless steel .... 0.00005
                               galvanized steel ... 0.0006
                               plastic, pvc ....... 0.0001

VISCOSITY OF WATER  .0000121

% REDUCTION OF SEEPAGE FLOW BENEATH LEVEE

WELL TOP HEIGHT  .33                         <Esc> exit screen
```

```
RELIEF WELL UNIT COST INPUT

DRILLING THROUGH TOP STRATUM       20

DRILLING THROUGH FOUNDATION        16

RISER PIPE                         30           stainless steel .... 80.00
                                                galvanized steel ... 40.00
                                                plastic, pvc ....... 30.00

WELL SCREEN                        85           stainless steel .... 125.00
                                                galvanized steel ... 75.00
                                                plastic, pvc ....... 85.00

FILTER                             12

BACKFILLING                        400

WELL COVER                         300

WELL DEVELOPMENT AND TEST          1000         <Esc> exit screen
```

Figure B3. Levee underseepage analysis control measure and unit cost input

```
PROJECT NAME : EXAMPLE OF 3 LAYER FOUNDATION
STATION      : CROSS 6

                      INITIAL CONDITIONS
                      ------------------

X1 =   424.76 FT
X3 =   434.17 FT
M  =  0.0278
I  =  2.0120
Qs =    386.17 GPM/100 FT

HO   =   12.07 FT
$    =  0.1961082
?
```

Figure B4. Levee underseepage analysis initial conditions calculations

```
STATION : CROSS 6

      OUTPUT DATA FOR RELIEF WELL ANALYSIS
      ------------------------------------

X1 =   424.76 FT
X3 =   434.17 FT
M  = UNDEFINED
I  = UNDEFINED
Qs =    385.76 GPM/100 FT
J  =  0  %
```

P ft	ASEL ft	WBAR ft	QW gal/100 ft	COST $
0.25	49.66	41.09	214.93	13378.45
0.38	64.36	50.91	266.85	12046.62
0.50	75.49	60.73	311.35	11739.94
0.63	84.68	70.55	377.05	11775.61
0.75	92.25	80.36	433.49	12012.04
0.88	98.59	90.18	482.10	12364.60
1.00	103.95	100.00	484.78	12794.67
0.50	75.49	60.73	311.35	11739.94

?

Figure B5. Control measure calculations relief well analysis

PROJECT NAME : EXAMPLE OF 3 LAYER FOUNDATION
STATION : CROSS 6

INITIAL CONDITIONS

X1 = 424.76 FT
X3 = 434.17 FT
M = 0.0278
I = 2.0120
Qs = 386.17 GPM/100 FT

H0 = 12.07 FT
$ = 0.1961

OUTPUT DATA FOR RELIEF WELL ANALYSIS

X1 = 424.76 FT
X3 = 434.17 FT
M = UNDEFINED
I = UNDEFINED
Qs = 385.76 GPM/100 FT
J = 0 %

P ft	ASEL ft	WBAR ft	QW gal/100 ft	COST $
0.25	49.66	41.09	214.93	13378.45
0.38	64.36	50.91	266.85	12046.62
0.50	75.49	60.73	311.35	11739.94
0.63	84.68	70.55	377.05	11775.61
0.75	92.25	80.36	433.49	12012.04
0.88	98.59	90.18	482.10	12364.60
1.00	103.95	100.00	484.78	12794.67
0.50	75.49	60.73	311.35	11739.94

COST SUMMARY FOR ALL CONTROL MEASURES

TYPE	VOLUME CU YD/100 FT	UNIT COST $	TOTAL $
RIVERSIDE BLANKET	0.00	1.20	0.00

CUTOFF

DC/D = 0
DEPTH = 0.00 FT
TOTAL = 0.00 $

RELIEF WELL - LOWEST COST

DEPTH = 60.73 FT
SPACING = 75.49 FT
TOTAL = 11739.94 $

Figure B6. Levee underseepage analysis summary of calculations

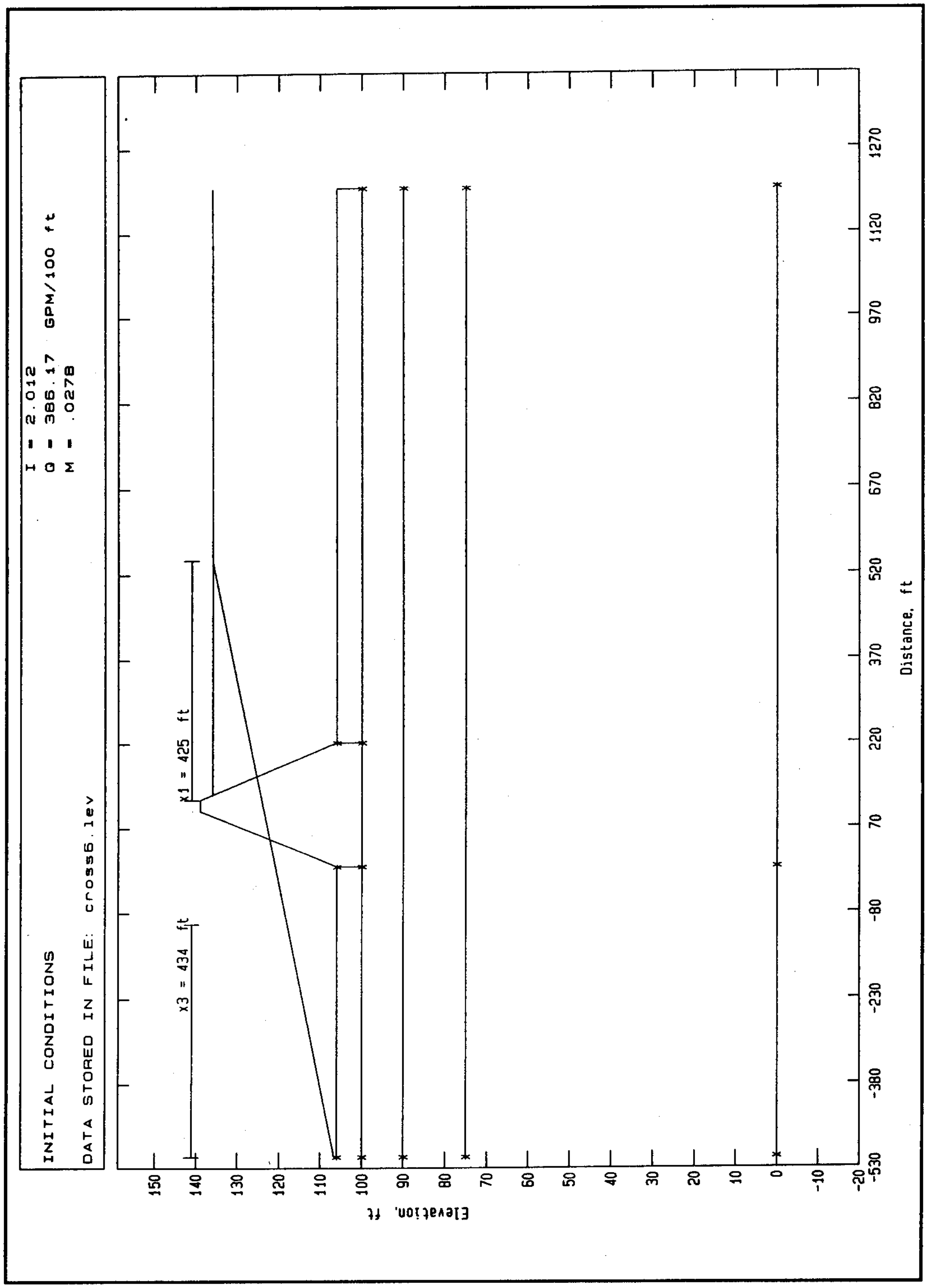


Figure B7. Initial conditions

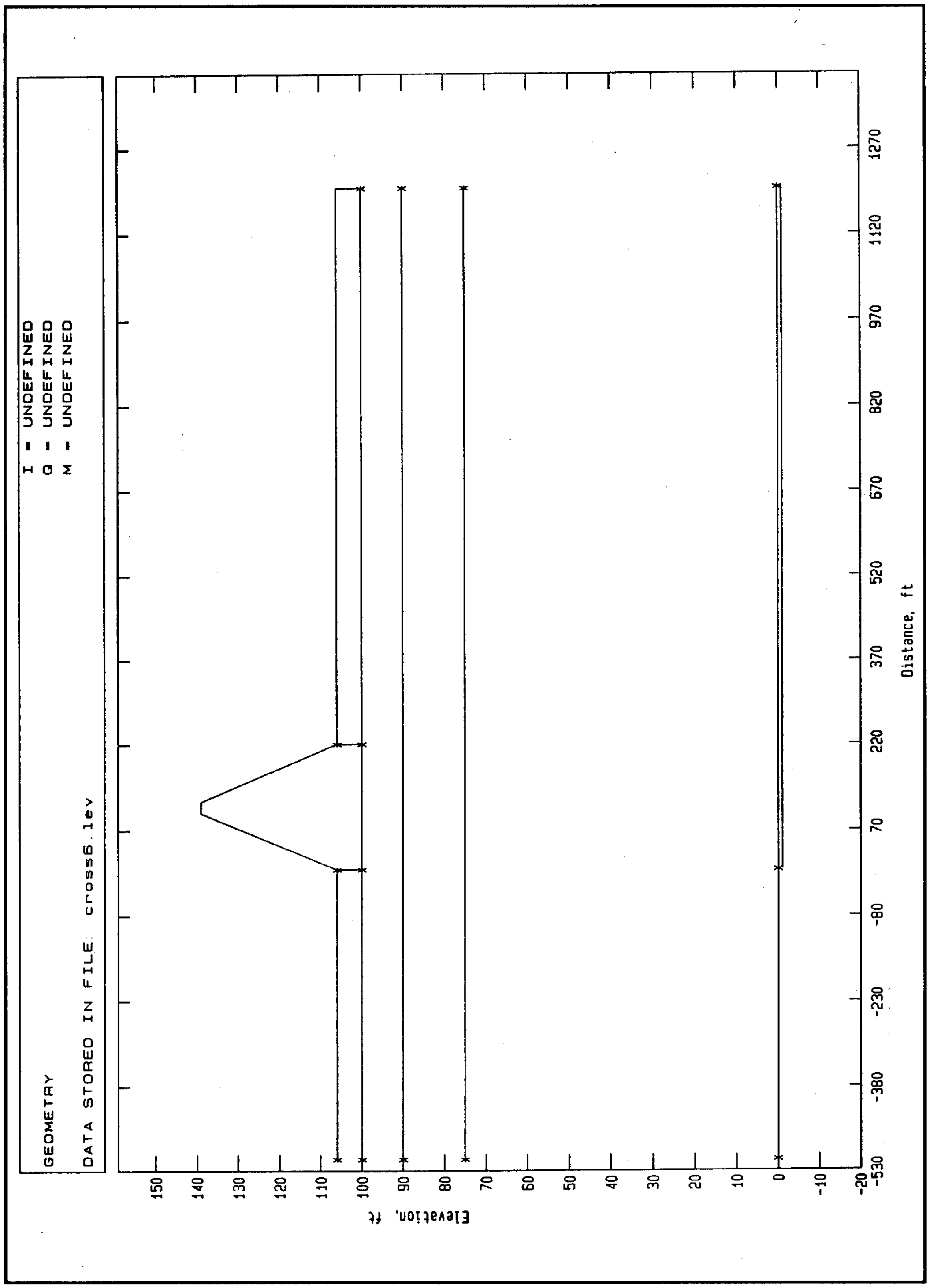


Figure B8. Geometry

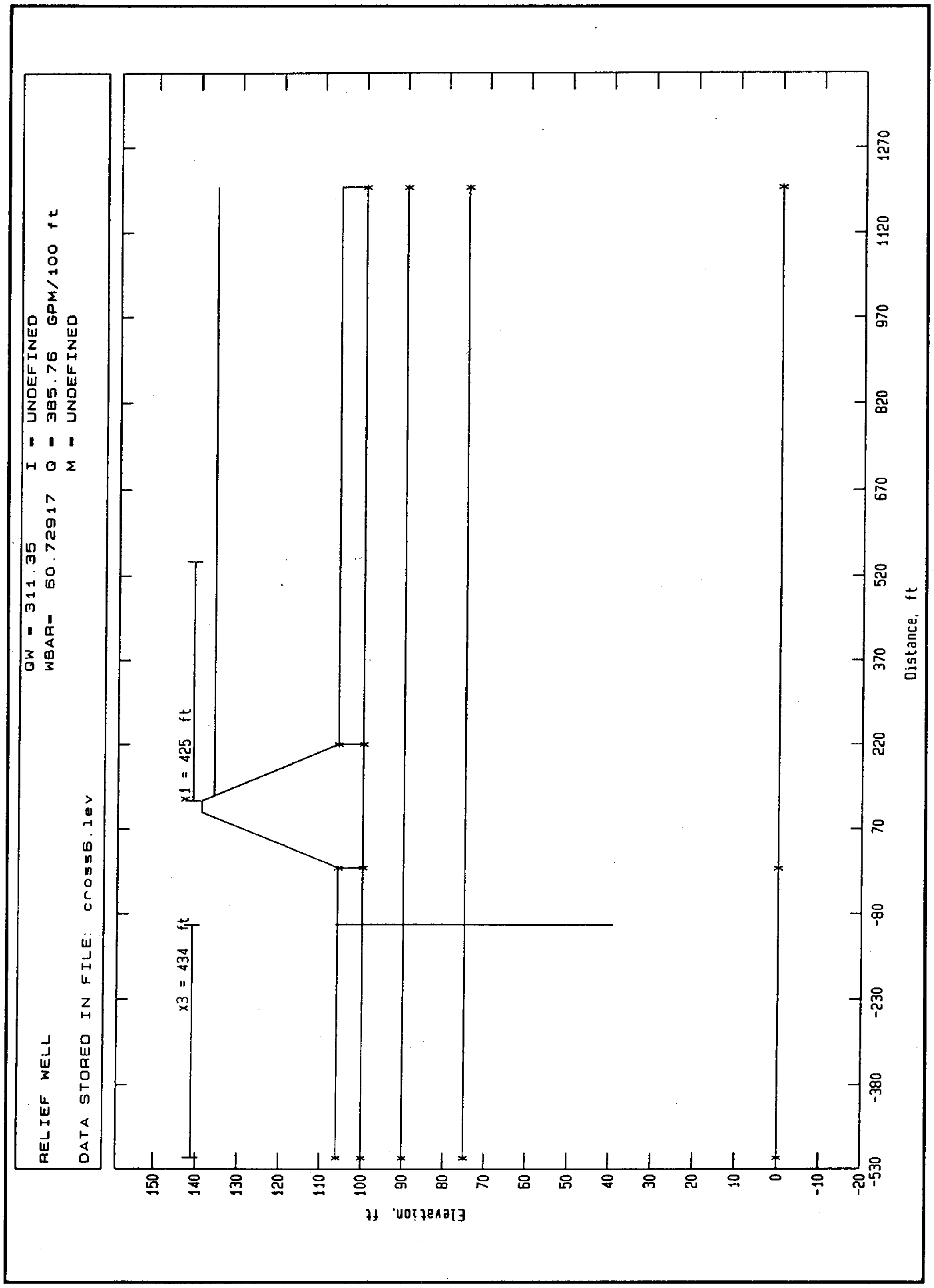


Figure B9. Relief well

Appendix C: Example Problem from File (Cross Section 7 - Rock Island District Example)

This example problem illustrates the analysis of a Rock Island District example problem. This example problem analyzes for initial conditions, a sand berm, a Rock Island berm, a riverside blanket, a cutoff, and relief wells. The input and results of this analysis are included in this appendix along with graphic output. To access the file, the user should start the program by typing LEVSEEP followed by the <enter> command. The program will initialize, and the main menu will appear. Under the INPUT/EDIT DATA from FILE menu heading is the Load File command. The user should type "L" and <enter> and then enter the file name "cross7" when prompted. The user may access and view the input data under the INPUT/EDIT from Keyboard options.

```
                GEOTECHNICAL DATA INPUT/EDIT SCREEN

PROJECT NAME   ROCK ISLAND DISTRICT EXAMPLE

STATION #  CROSS 7          LANDSIDE TOE ELEV   453.7

LANDSIDE TOE OFFSET                  RIVERSIDE TOE OFFSET   180

NET HEAD ON LEVEE  22.3            RIVERWARD EXTENT OF TOP STRATUM  200

LANDWARD EXTENT OF TOP STRATUM  infinite      ENTRANCE  open

EXIT  infinite       SUBMERGED WEIGHT   53

NUMBER OF LAYERS COMPOSING PERVIOUS FOUNDATION   1

NUMBER OF LAYERS COMPOSING LANDSIDE STRATA    1

NUMBER OF LAYERS COMPOSING RIVERSIDE STRATA   1
                                              <Esc> exit screen
```

Figure C1. Levee underseepage analysis geotechnical properties input (Continued)

SUBSTRATUM PERMEABILITY DATA (AVERAGED)	
COEFFICENT OF PERMEABILITY	.15
EFFECTIVE THICKNESS OF PERVIOUS SUBSTRATUM	108
ACTUAL DEPTH OF PERVIOUS SUBSTRATUM	108

<Esc> exit screen

LANDSIDE AND RIVERSIDE PERMEABILITY DATA (AVERAGED)	
EFFECTIVE THICKNESS OF LANDSIDE TOP STRATUM	7.4
PERMEABILITY OF LANDSIDE TOP STRATUM	.0015
EFFECTIVE THICKNESS OF RIVERSIDE TOP STRATUM	6.9
PERMEABILITY OF RIVERSIDE TOP STRATUM	.00075
EFFECTIVE THICKNESS FOR UPLIFT	7.4
TOP STRATUM THICKNESS	7.4

<Esc> exit screen

Figure C1. (Concluded)

CROSS SECTION DATA INPUT SCREEN

LINE#	X	Y	lINE#	X	Y	LINE#	X	Y
1	380	456.3	2	380	456.3	3	-490	338.3
1	180	456.3	2	380	449.4	4	180	456.3
1	98	476	2	100	449.4	4	180	449.4
1	85	476	2	33	446.3	5		453.7
1		453.7	2	-490	446.3	5		446.3
1	-490	453.7	3	380	338.3			

POINT NUMBER : 1
SCREEN 1 OF 2

<Esc> exit screen
<^PgUp> previous screen
<^PgDn> next screen

Figure C2. Levee underseepage analysis cross-section input

```
BERM CONTROL MEASURE INPUT

FACTOR OF SAFETY FOR BERM
                                INPUT HERE WILL CAUSE PROGRAM TO CALCULATE
                                LEVEE LANDSIDE TOE ALL. UPWARD GRADIENT

LEVEE LANDSIDE TOE ALLOWABLE UPWARD GRADIENT  .34

BERM LANDSIDE TOE ALLOWABLE UPWARD GRADIENT  .8

LANDSIDE SLOPE OF LEVEE  .26

SLOPE AT BERM TOE  .2

                                                  <Esc> exit screen
```

```
RIVERSIDE BLANKET CONTROL INPUT

BLANKET LANDSIDE TOE ALLOWABLE UPWARD GRADIENT .7

SLOPE AT TRIANGULAR RIVERSIDE BLANKET TOE  .2

RIVERSIDE LEVEE AVERAGE SLOPE .25

                                                  <Esc> exit screen
```

Figure C3. Levee underseepage analysis control measure and unit cost input (Sheet 1 of 4)

```
RELIEF WELL CONTROL INPUT

SAFETY FACTOR FOR WELL  1.5          INPUT HERE WILL CAUSE PROGRAM TO CALC
                                     LEVEE LANDSIDE TOE ALL. UPWARD GRADIENT

LEVEE LANDSIDE TOE ALLOWABLE UPWARD GRADIENT  .5662393

EFFECTIVE WELL RADIUS 1

INSIDE WELL PIPE DIAMETER  .67

COEFFICIENT OF PIPE ROUGHNESS  .0001
                               stainless steel .... 0.00005
                               galvanized steel ... 0.0006
                               plastic, pvc ........0.0001

VISCOSITY OF WATER  .0000121

% REDUCTION OF SEEPAGE FLOW BENEATH LEVEE

WELL TOP HEIGHT  .33                        <Esc> exit screen
```

```
BERM UNIT COST INPUT

UNSPECIFIED BERM        1.3

IMPERVIOUS BERM         1.3

SEMIPERVIOUS BERM       1.3

SAND BERM               3.75

PERVIOUS BERM WITH A COLLECTOR PIPE  3.75

ROCK ISLAND BERM        3.75

                                            <Esc> exit screen
```

Figure C3. (Sheet 2 of 4)

CUTOFF COST MENU

USE DEFAULTS yes

$ 3.00 ABOVE 65 FEET

$ 8.00 BELOW 65 FEET

<Esc> exit screen

RIVERSIDE BLANKET UNIT COST INPUT

BLANKET UNIT COST 1.2

<Esc> exit screen

Figure C3. (Sheet 3 of 4)

```
                    RELIEF WELL UNIT COST INPUT

DRILLING THROUGH TOP STRATUM      20

DRILLING THROUGH FOUNDATION       16

RISER PIPE                        30          stainless steel .... 80.00
                                              galvanized steel ... 40.00
                                              plastic, pvc ....... 30.00

WELL SCREEN                       85          stainless steel .... 125.00
                                              galvanized steel ... 75.00
                                              plastic, pvc ....... 85.00

FILTER                            12

BACKFILLING                       400

WELL COVER                        300

WELL DEVELOPMENT AND TEST         1000        <Esc> exit screen
```

Figure C3. (Sheet 4 of 4)

```
PROJECT NAME : ROCK ISLAND DISTRICT EXAMPLE
STATION      : CROSS 7

                         INITIAL CONDITIONS
                         ------------------

X1 =   183.84 FT
X3 =   282.70 FT
M  =  0.0345
I  =  1.3177
Qs =    823.36 GPM/100 FT

H0   =    9.75 FT
$    =  0.1670426
?
```

Figure C4. Levee underseepage analysis initial conditions calculation

```
                         BLANKET ANALYSIS
                         ----------------

 IS THERE A BORROW PIT? (Y/N)
? N




               RIVERSIDE BLANKET ANALYSIS
               --------------------------

 XR =    754.33
 L1 =    200.00

IF XR OR LB > DISTANCE TO RIVER, SOLUTION INFEASIBLE

 DO YOU WANT TO CONTINUE? (Y/N)
? N
```

Figure C5. Control measure calculations blanket analysis

```
BERM (B)
RIVERSIDE BLANKET (R)
CUTOFF (C)
WELL (W)
```

```
                BERM SELECTION MENU

  1. IMPERVIOUS BERM
  2. SEMIPERVIOUS BERM
  3. PERVIOUS BERM WITH COLLECTOR PIPE
  4. SAND BERM
  5. ROCK ISLAND BERM

  ENTER NUMBER OF CHOICE ===>
? 4


  PROJECT : ROCK ISLAND DISTRICT EXAMPLE
  STATION : CROSS 7

                      OUTPUT DATA FOR BERM ANALYSIS
                      -----------------------------

SAND BERM
 X1 =    183.84 FT
 X3 = UNDEFINED
 M  = UNDEFINED
 I  = UNDEFINED
 Qs = UNDEFINED

 XS =    174.37 FT
 T  =      7.43 FT
 VB =      3358.25 CU YD/100 FT
?


                BERM COST CALCULATION
                ---------------------

SAND BERM
 VB          =      3358.25 CU YD/100 FT
 UNIT COST   = $       3.75 /CU YD
 TOTAL COST  = $   12593.45 /100 FT LEVEE STATION
?
```

Figure C6. Control measure calculations berm analysis (Continued)

```
                BERM SELECTION MENU

  1. IMPERVIOUS BERM
  2. SEMIPERVIOUS BERM
  3. PERVIOUS BERM WITH COLLECTOR PIPE
  4. SAND BERM
  5. ROCK ISLAND BERM

 ENTER NUMBER OF CHOICE ===>
? 5

 CW : CREEP RATIO (DEFAULT=10) ===>
? 10




 PROJECT : ROCK ISLAND DISTRICT EXAMPLE
 STATION : CROSS 7
                    OUTPUT DATA FOR BERM ANALYSIS
                    -----------------------------

ROCK ISLAND BERM
 X1 =   183.84 FT
 X3 = UNDEFINED
 M  = UNDEFINED
 I  = UNDEFINED
 Qs = UNDEFINED

 XRI=    43.00 FT
 T  =     3.12 FT
 VB =      522.34 CU YD/100 FT
?




               BERM COST CALCULATION
               ---------------------

ROCK ISLAND BERM
 VB         =      522.34 CU YD/100 FT
 UNIT COST  = $       3.75 /CU YD
 TOTAL COST = $    1958.78 /100 FT LEVEE STATION
?
```

Figure C6. (Concluded)

```
                    CUTOFF ANALYSIS
                    ---------------

DC/D : CUTOFF DEPTH/DEPTH RATIO ===>
? .95




PROJECT : ROCK ISLAND DISTRICT EXAMPLE
STATION : CROSS 7
               OUTPUT DATA FOR CUTOFF ANALYSIS
               -------------------------------

DC/D = .95

X1 =   183.84 FT
X3 =   282.70 FT
M  =  0.0291
I  =  1.0231
Qs =     489.09 GPM/100 FT
?




               CUTOFF COST CALCULATION
               -----------------------

DEPTH =  110.00
COST  = $   55500.00 /100 FT OF LEVEE STATION
?
```

Figure C7. Control measure calculations cutoff analysis

```
STATION : CROSS 7

      OUTPUT DATA FOR RELIEF WELL ANALYSIS
      ------------------------------------

X1 =   183.84 FT
X3 =   282.70 FT
M  = UNDEFINED
I  = UNDEFINED
Qs =     822.49 GPM/100 FT
J  =  0  %
```

P ft	ASEL ft	WBAR ft	QW gal/100 ft	COST $
0.25	57.11	27.00	350.87	8966.86
0.38	70.04	40.50	538.17	9489.32
0.50	79.65	54.00	573.57	10259.31
0.63	86.70	67.50	679.54	11184.78
0.75	91.52	81.00	757.78	12263.48
0.88	94.77	94.50	814.10	13451.46
1.00	96.91	108.00	853.20	14729.53
0.25	57.11	27.00	350.87	8966.86

?

Figure C8. Control measure calculations relief well analysis

```
PROJECT NAME : ROCK ISLAND DISTRICT EXAMPLE
STATION      : CROSS 7

                          INITIAL CONDITIONS
                          ------------------

X1 =   183.84 FT
X3 =   282.70 FT
M  =  0.0345
I  =  1.3177
Qs =  823.36 GPM/100 FT

HO   =    9.75 FT
$    =  0.1670


                       OUTPUT DATA FOR BERM ANALYSIS
                       -----------------------------

SAND BERM

 X1 =    183.84 FT
 X3 = UNDEFINED
 M  = UNDEFINED
 I  = UNDEFINED
 Qs = UNDEFINED

 X  =    174.37 FT
 T  =      7.43 FT

ROCK ISLAND BERM

 X1 =    183.84 FT
 X3 = UNDEFINED
 M  = UNDEFINED
 I  = UNDEFINED
 Qs = UNDEFINED

 X  =     43.00 FT
 T  =      3.12 FT
```

Figure C9. Levee underseepage analysis summary of calculations (Sheet 1 of 3)

OUTPUT DATA FOR BLANKET ANALYSIS

```
X1 =   183.84 FT
X3 =   282.70 FT
M  = UNDEFINED
I  = UNDEFINED
Qs = UNDEFINED

XR  =   754.33 FT
LB  =     0.00 FT
KB  =  0.0000
ZB  =     0.00 FT
```

OUTPUT DATA FOR CUTOFF ANALYSIS

```
X1 =   183.84 FT
X3 =   282.70 FT
M  =  0.0291
I  =  1.0231
Qs =  489.09 GPM/100 FT

DC/D = .95
```

OUTPUT DATA FOR RELIEF WELL ANALYSIS

```
X1 =   183.84 FT
X3 =   282.70 FT
M  = UNDEFINED
I  = UNDEFINED
Qs =  822.49 GPM/100 FT
J  =  0  %
```

P ft	ASEL ft	WBAR ft	QW gal/100 ft	COST $
0.25	57.11	27.00	350.87	8966.86
0.38	70.04	40.50	538.17	9489.32
0.50	79.65	54.00	573.57	10259.31
0.63	86.70	67.50	679.54	11184.78
0.75	91.52	81.00	757.78	12263.48
0.88	94.77	94.50	814.10	13451.46
1.00	96.91	108.00	853.20	14729.53
0,25	57.11	27.00	350.87	8966.86

Figure C9. (Sheet 2 of 3)

COST SUMMARY FOR ALL CONTROL MEASURES

TYPE	VOLUME CU YD/100 FT	UNIT COST $	TOTAL $
SAND BERM	3358.25	3.75	12593.45
ROCK ISLAND BERM	522.34	3.75	1958.78
RIVERSIDE BLANKET	0.00	1.20	0.00

CUTOFF

DC/D = .95
DEPTH = 110.00 FT
TOTAL = 55500.00 $

RELIEF WELL - LOWEST COST

DEPTH = 27.00 FT
SPACING = 57.11 FT
TOTAL = 8966.86 $

Figure C9. (Sheet 3 of 3)

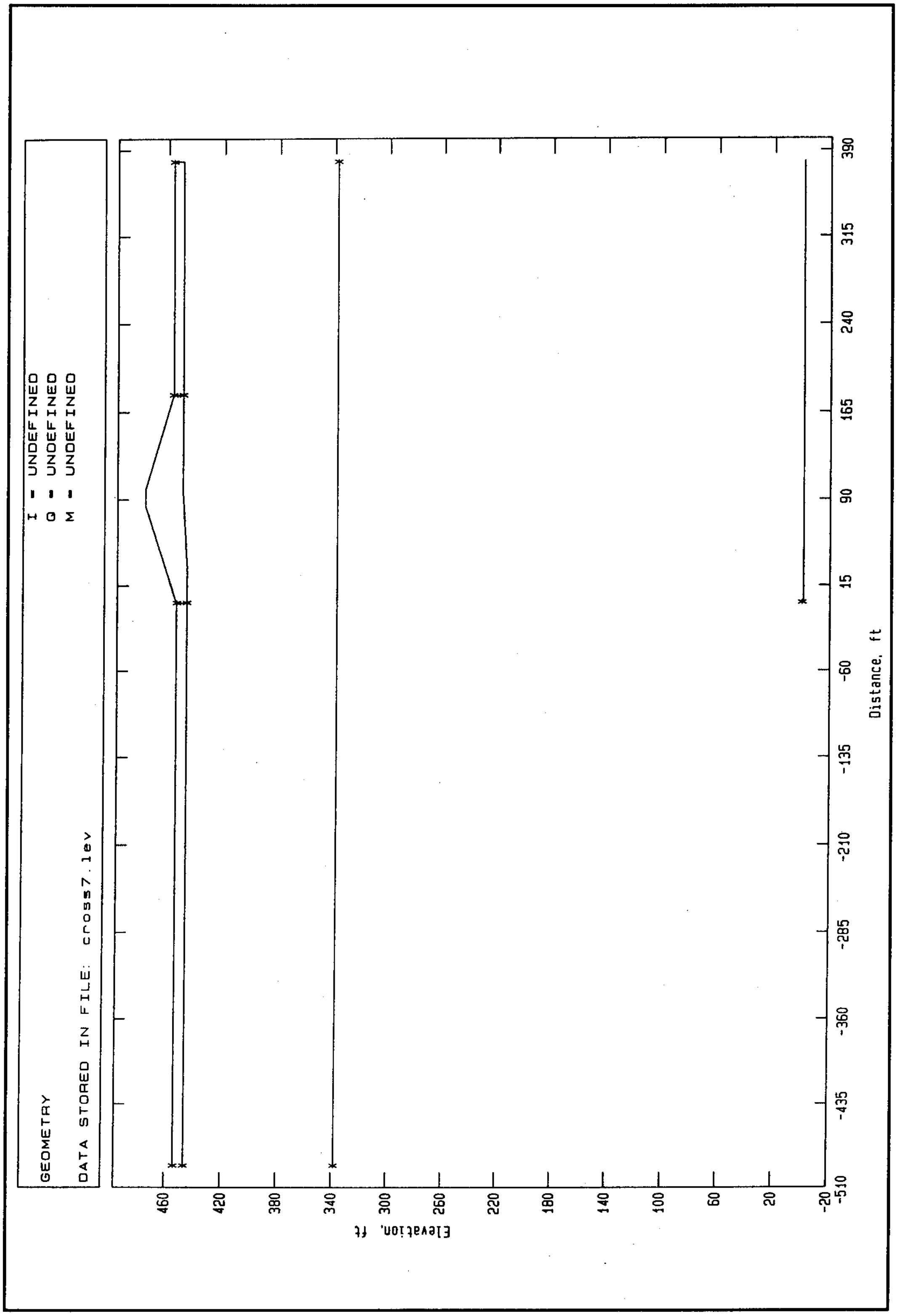


Figure C10. Geometry

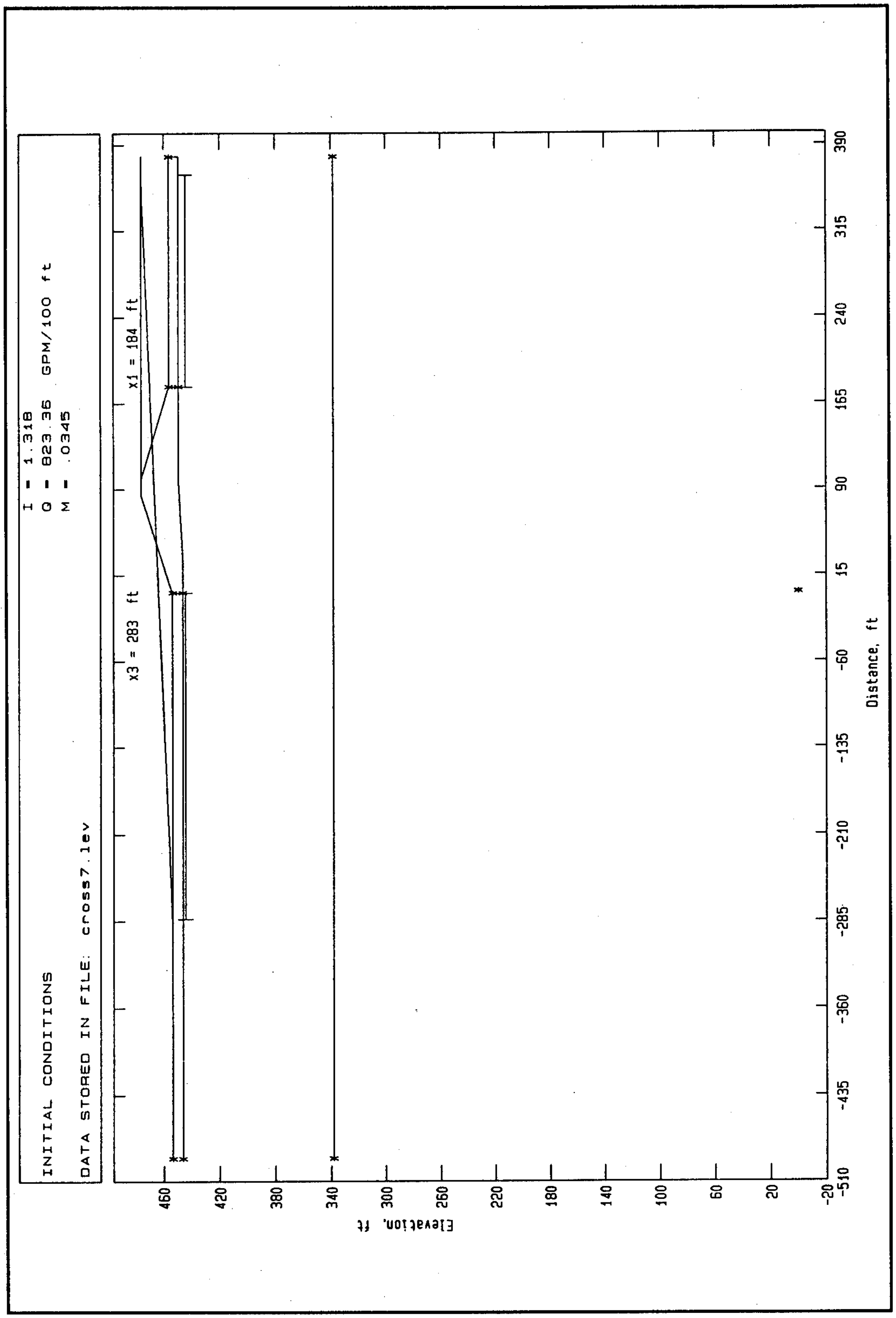


Figure C11. Initial conditions

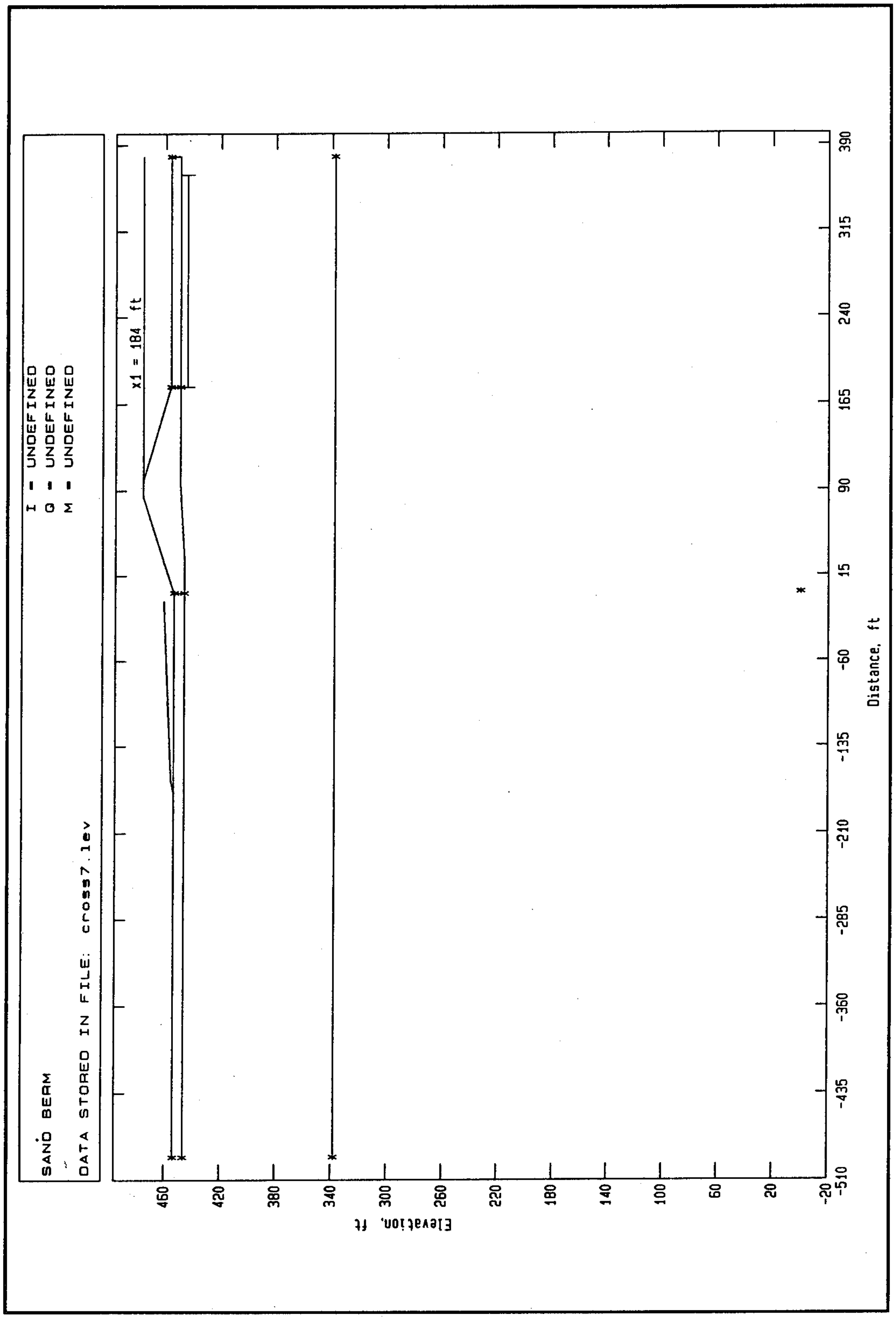


Figure C12. Sand berm

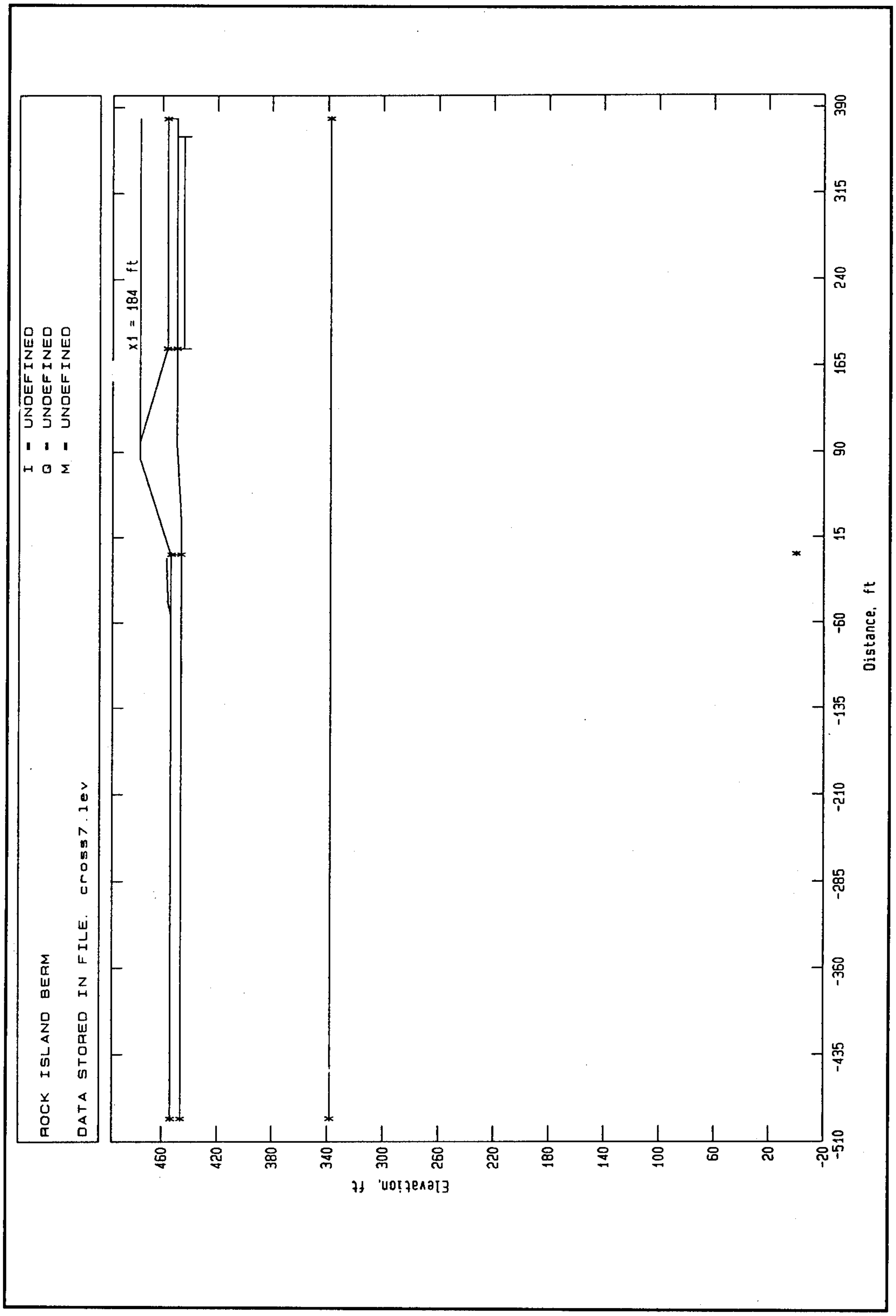


Figure C13. Rock Island berm

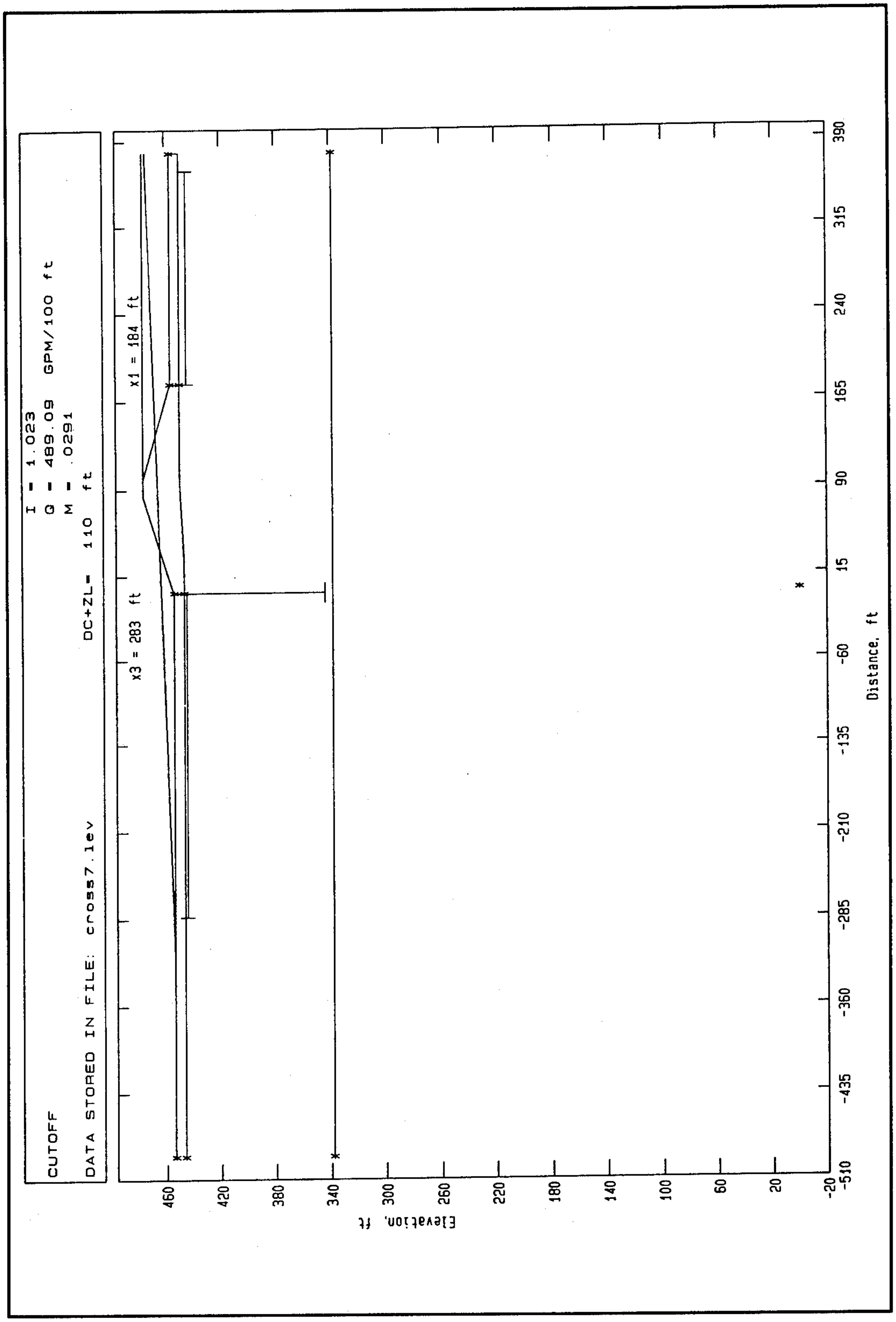


Figure C14. Cutoff

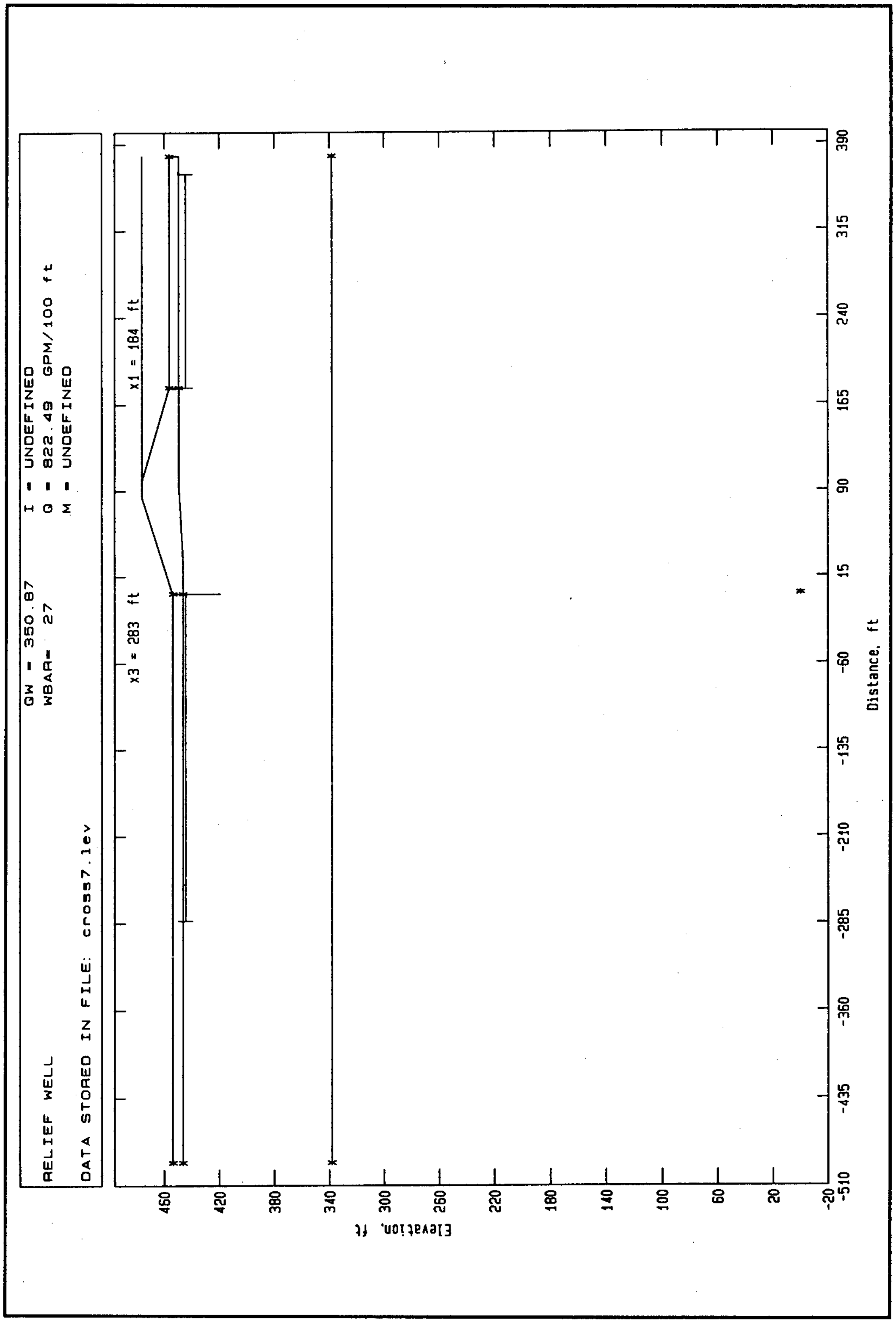


Figure C15. Relief well

Appendix D: Example Problem with Parameter Study (Cross Section 8 - Magnolia Levee, Huntington District)

This appendix consists of a representative problem of cross section 1 at Magnolia Levee, Ohio. The complete results of these analyses are presented in Chapter 4 of this report.

The discussion of the results of these parameter studies is included in Chapter 4 of this report. The input data, geometry, analysis results, and output from LEVSEEP are found in this appendix.

```
                    GEOTECHNICAL DATA INPUT/EDIT SCREEN
PROJECT NAME   MAGNOLIA LEVEE, OHIO

STATION #  SECTION A      LANDSIDE TOE ELEV   948.2

LANDSIDE TOE OFFSET  86             RIVERSIDE TOE OFFSET   86

NET HEAD ON LEVEE  27.8          RIVERWARD EXTENT OF TOP STRATUM  200

LANDWARD EXTENT OF TOP STRATUM  175          ENTRANCE  open

EXIT  open            SUBMERGED WEIGHT   50


NUMBER OF LAYERS COMPOSING PERVIOUS FOUNDATION   1

NUMBER OF LAYERS COMPOSING LANDSIDE STRATA    1

NUMBER OF LAYERS COMPOSING RIVERSIDE STRATA   1
                                              <Esc> exit screen
```

Figure D1. Levee underseepage analysis geotechnical properties input (Continued)

```
SUBSTRATUM PERMEABILITY DATA (AVERAGED)

COEFFICENT OF PERMEABILITY                    .01

EFFECTIVE THICKNESS OF PERVIOUS SUBSTRATUM    100

ACTUAL DEPTH OF PERVIOUS SUBSTRATUM           100

                                     <Esc> exit screen

      AVERAGE HORIZONTAL CM/SEC
```

```
LANDSIDE AND RIVERSIDE PERMEABILITY DATA (AVERAGED)

EFFECTIVE THICKNESS OF LANDSIDE TOP STRATUM  7

PERMEABILITY OF LANDSIDE TOP STRATUM         .0001

EFFECTIVE THICKNESS OF RIVERSIDE TOP STRATUM 7

PERMEABILITY OF RIVERSIDE TOP STRATUM        .0001

EFFECTIVE THICKNESS FOR UPLIFT               7

TOP STRATUM THICKNESS                        7

                                     <Esc> exit screen

      FT
```

Figure D1. (Concluded)

CROSS SECTION DATA INPUT SCREEN

LINE#	X	Y	lINE#	X	Y	LINE#	X	Y
1	0	948.2	1	347	948.2	4	0	841.2
1	175	948.2	1	2347	948.2	4	2347	841.2
1	191	950	2	175	948.2			
1	256	977	2	347	948.2			
1	266	977	3	0	941.2			
1	331	950	3	2347	941.2			

POINT NUMBER : 13
SCREEN 1 OF 1

<Esc> exit screen
<^PgUp> previous screen
<^PgDn> next screen

Figure D2. Levee underseepage analysis cross-section input

```
                    RELIEF WELL CONTROL INPUT
SAFETY FACTOR FOR WELL                INPUT HERE WILL CAUSE PROGRAM TO CALC
                                      LEVEE LANDSIDE TOE ALL. UPWARD GRADIENT

LEVEE LANDSIDE TOE ALLOWABLE UPWARD GRADIENT  .53

EFFECTIVE WELL RADIUS 1

INSIDE WELL PIPE DIAMETER  .67

COEFFICIENT OF PIPE ROUGHNESS  .0001
                               stainless steel .... 0.00005
                               galvanized steel ... 0.0006
                               plastic, pvc ....... 0.0001

VISCOSITY OF WATER  .0000121

% REDUCTION OF SEEPAGE FLOW BENEATH LEVEE  1

WELL TOP HEIGHT  .33                        <Esc> exit screen
```

```
                    RELIEF WELL UNIT COST INPUT
DRILLING THROUGH TOP STRATUM      20

DRILLING THROUGH FOUNDATION       16

RISER PIPE                        30           stainless steel .... 80.00
                                               galvanized steel ... 40.00
                                               plastic, pvc ....... 30.00

WELL SCREEN                       85           stainless steel .... 125.00
                                               galvanized steel ... 75.00
                                               plastic, pvc ....... 85.00

FILTER                            12

BACKFILLING                       400

WELL COVER                        300

WELL DEVELOPMENT AND TEST         1000         <Esc> exit screen
      $/FT
```

Figure D3. Levee underseepage analysis control measure and unit cost input

```
PROJECT NAME : MAGNOLIA LEVEE, OHIO
STATION      : SECTION A

                    INITIAL CONDITIONS
                    ------------------

X1 =   168.98 FT
X3 =   153.27 FT
M  =  0.0562
I  =  1.2316
Qs =      82.88 GPM/100 FT

HO    =     8.62 FT
$     =  0.2023266
?
```

Figure D4. Levee underseepage analysis initial conditions calculation

```
STATION : SECTION A

      OUTPUT DATA FOR RELIEF WELL ANALYSIS
      ------------------------------------

X1 =   168.98 FT
X3 =   153.27 FT
M  = UNDEFINED
I  = UNDEFINED
Qs =     82.80 GPM/100 FT
J  =  0  %
```

P ft	ASEL ft	WBAR ft	QW gal/100 ft	COST $
0.25	55.47	25.00	27.28	8787.77
0.38	67.57	37.50	41.70	9305.67
0.50	77.77	50.00	48.00	9900.51
0.63	87.69	62.50	59.96	10391.94
0.75	95.95	75.00	70.69	10969.75
0.88	103.63	87.50	72.67	11518.86
1.00	110.91	100.00	81.72	12036.92
0.25	55.47	25.00	27.28	8787.77

?

Figure D5. Control measure calculations relief well analysis

```
PROJECT NAME : MAGNOLIA LEVEE, OHIO
STATION      : SECTION A

                     INITIAL CONDITIONS
                     ------------------

X1 =   168.98 FT
X3 =   153.27 FT
M  =  0.0562
I  =  1.2316
Qs =   82.88 GPM/100 FT

HO    =      8.62 FT
$     =  0.2023

          OUTPUT DATA FOR RELIEF WELL ANALYSIS
          -----------------------------------

X1 =   168.98 FT
X3 =   153.27 FT
M  = UNDEFINED
I  = UNDEFINED
Qs =   82.80 GPM/100 FT
J  =  0  %
```

P ft	ASEL ft	WBAR ft	QW gal/100 ft	COST $
0.25	55.47	25.00	27.28	8787.77
0.38	67.57	37.50	41.70	9305.67
0.50	77.77	50.00	48.00	9900.51
0.63	87.69	62.50	59.96	10391.94
0.75	95.95	75.00	70.69	10969.75
0.88	103.63	87.50	72.67	11518.86
1.00	110.91	100.00	81.72	12036.92
0.25	55.47	25.00	27.28	8787.77

COST SUMMARY FOR ALL CONTROL MEASURES

TYPE	VOLUME CU YD/100 FT	UNIT COST $	TOTAL $
RIVERSIDE BLANKET	0.00	1.20	0.00

```
CUTOFF
------
DC/D =      0
DEPTH =         0.00 FT
TOTAL =            0.00 $

RELIEF WELL - LOWEST COST
-------------------------
DEPTH =         25.00 FT
SPACING =       55.47 FT
TOTAL =          8787.77 $
```

Figure D6. Levee underseepage analysis summary of calculations

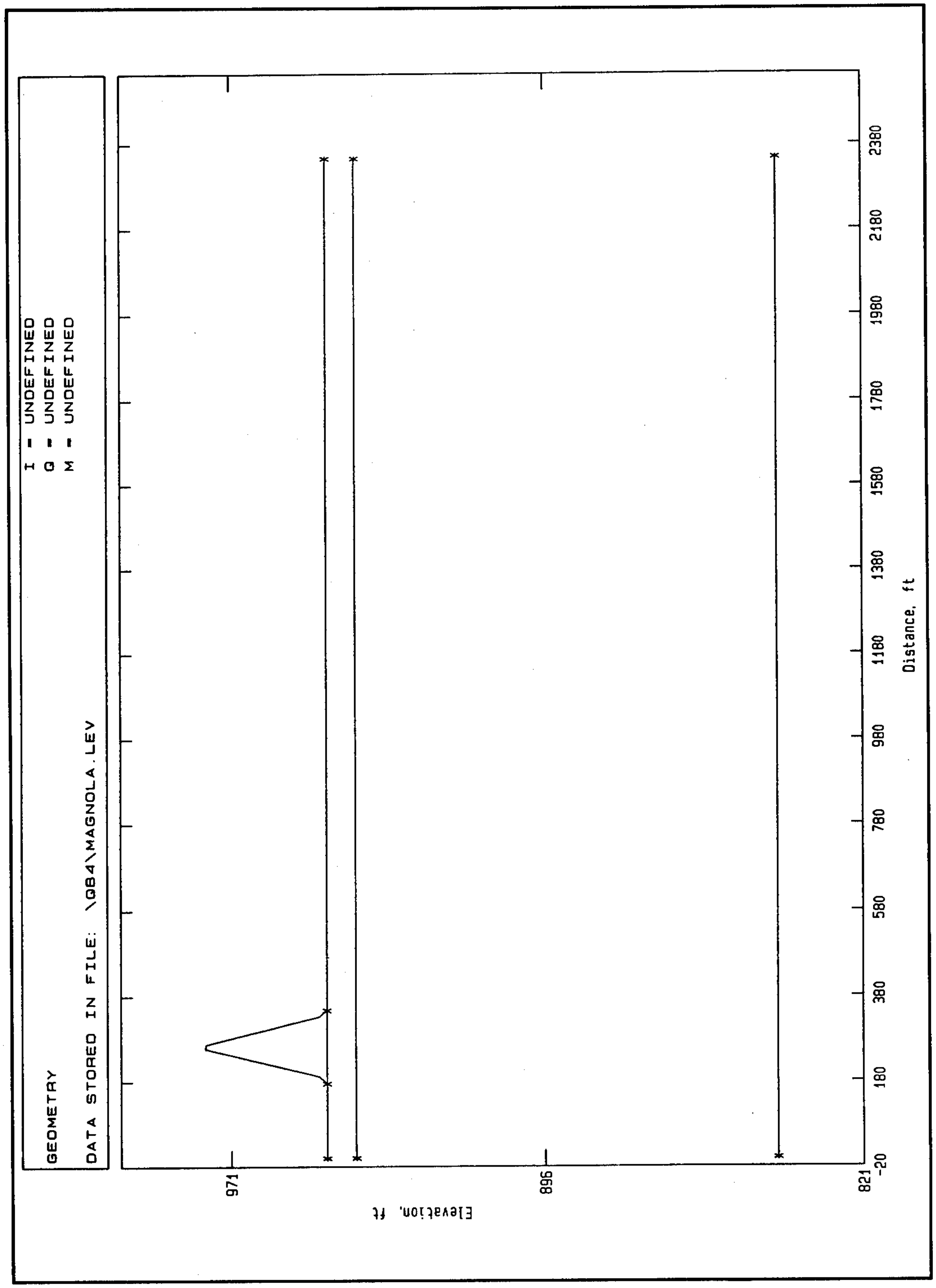


Figure D7. Geometry

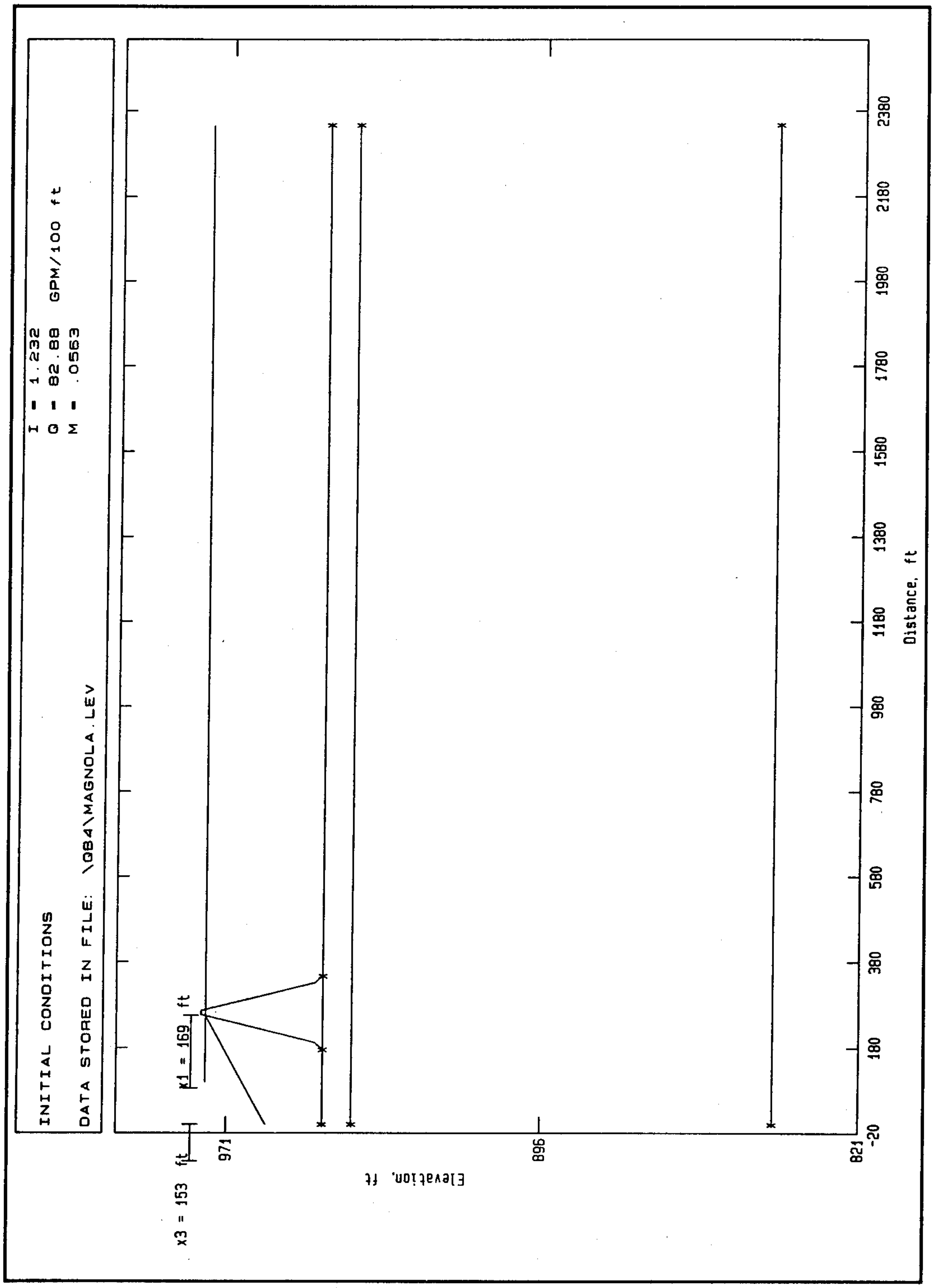


Figure D8. Initial conditions

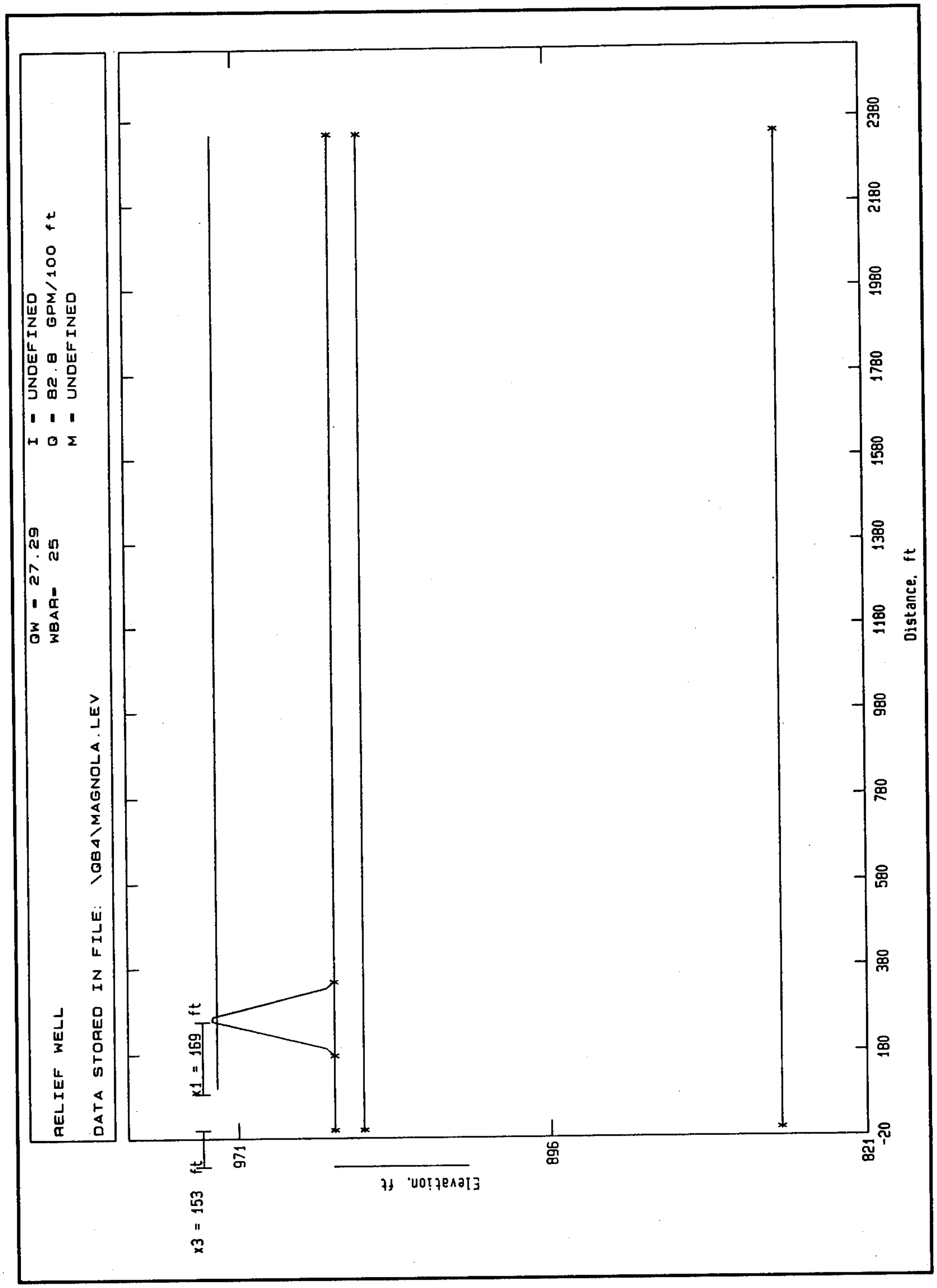


Figure D9. Relief well

Appendix E: Default Unit Costs

This appendix provides a listing of the default unit costs in LEVSEEP. Those default unit costs are as follows:

```
BERM UNIT COST INPUT

UNSPECIFIED BERM       1.3

IMPERVIOUS BERM        1.3

SEMIPERVIOUS BERM      1.3

SAND BERM              3.75

PERVIOUS BERM WITH A COLLECTOR PIPE  3.75

ROCK ISLAND BERM       3.75



                                    <Esc> exit screen
      $/CU YD
```

Figure E1. Berm unit cost input

```
RIVERSIDE BLANKET UNIT COST INPUT

BLANKET UNIT COST                1.2



                                    <Esc> exit screen
      $/CU YD
```

Figure E2. Riverside blanket unit cost input

```
                    RELIEF WELL UNIT COST INPUT
DRILLING THROUGH TOP STRATUM      20
DRILLING THROUGH FOUNDATION       16
RISER PIPE                        30        stainless steel .... 80.00
                                            galvanized steel ... 40.00
                                            plastic, pvc ....... 30.00
WELL SCREEN                       85        stainless steel .... 125.00
                                            galvanized steel ... 75.00
                                            plastic, pvc ....... 85.00
FILTER                            12
BACKFILLING                       400
WELL COVER                        300
WELL DEVELOPMENT AND TEST         1000      <Esc> exit screen
     $/FT
```

Figure E3. Relief well unit cost input

```
                         CUTOFF COST MENU

  USE DEFAULTS yes

  $ 3.00 ABOVE 65 FEET
  $ 8.00 BELOW 65 FEET

                                              <Esc> exit screen
       YES OR NO
```

Figure E4. Cutoff cost menu

Appendix F: History of LEVSEEP Development

Levee underseepage has been identified by the Corps of Engineers field personnel to be one of the high-priority soils-related problems being addressed in the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program (Scanlon et al. 1983). Seepage control measures include landside berms, riverside blankets, cutoffs, and relief wells. The technical guidance concerning these measures appears in EM 1110-2-1913 (1978) and U.S. Army Engineer Waterways Experiment Station (WES) (1956). Early in 1985, Corps field personnel indicated a specific need for a user-friendly, microcomputer-based analytic tool for use in analyzing these control measures.

On 26 June 1985, a contract was awarded to JAYCOR to develop levee underseepage analysis computer programs in accordance with the following tasks:

a. Adopt an existing plot program for a mainframe computer to a personal computer.

b. Extend the program to have additional plotting and calculating capability for underseepage analysis.

c. Develop a program capable for calculating the effect of various control measures on levee underseepage performance.

d. Develop a database to store graphic and tabular information generated by the programs.

e. Develop a program to compute construction quantities required for landside berms, riverside blankets, and cutoff control measures and to calculate costs for each measure.

f. Validate the programs with hand calculations and produce a user's guide for the programs.

The work described above was completed and reported to the WES (Cunny, Mlakar, and Agostinelli 1985).

In 1986, the need to expand the Levee Underseepage Analysis Program to include the analysis of relief wells for underseepage control was recognized. On 28 July 1986, a contract was awarded to JAYCOR to develop a relief well analysis computer program in accordance with the following:

a. Develop procedures for analysis of infinite relief well systems for levee underseepage control.

b. Incorporate the procedures for relief well analysis into the programs CONTROL and COST of the Levee Underseepage Analysis Program (Cunny, Mlakar, and Agostinelli 1985).

c. Validate the program with hand calculations and produce a report of validation and a user's guide for the program.

The work described above was completed and reported (Shockley et al. 1986).

In 1987, the WES authorized JAYCOR to combine the results of the previous two years work and make the following modifications and additions:

a. Input into a common file all general data for analysis of each of the control measures.

b. Rewrite the graphical output to use Micrographics Compatibility System library of subroutines (WES 1979) in lieu of the Micro TEMPLATE library.

c. Add an example problem representing a case history from the U.S. Army Engineer District, Rock Island, and add procedures used by the District for calculating berm dimensions.

In addition, the following items of an editorial and/or technical nature were incorporated in this work:

a. The program was completely reorganized to make solutions more direct and to improve the program's user-friendliness.

b. Plot routines were added for berms and blankets.

c. An option for calculating the transformed permeability of the top stratum was added.

d. An option to calculate allowable gradients based on submerged unit weight and factor of safety was added.

e. The minimum berm thickness was changed from 6.2 to 5.0 ft.

f. A default value of $3.75 for unit cost of a sand berm was added.

g. A single page summary of cost for various control measures for any one cross section was added.

h. The total depth of cutoffs and relief wells was corrected to include actual thickness rather than transformed thickness of the top stratum.

i. The procedure for calculating the thickness of a shortened berm was corrected to include a modified equation for uplift pressure.

j. The procedure for calculating entrance and exit distances was corrected for relief well analysis for the case of no top stratum.

k. Printed output was limited to significant figures, and wrap-arounds were eliminated.

l. A routine was added to determine that the thickness of a berm would not be so great that the berm slope would not intersect the landside levee slope.

The computer program developed in this effort, LEVSEEP, was written for the IBM PC and compatible computers using the MS DOS operating system (Microsoft Corporation 1983). The language used was Microsoft FORTRAN 77 (Version 3.31) (Microsoft Corporation 1984). Graphical displays were created using Micrographics Compatibility System (Version 3.1) library of subroutines (WES 1979). The key factors describing seepage flow and substratum hydrostatic pressures calculated by the program were saved in files which were compatible with the DBASE II or III software (Ashton-Tate 1984). This work was submitted by Cunny with a report to WES in 1987. This work was later published as Technical Report REMR-GT-13 (Cunny, Agostinelli, and Taylor 1989).

Revisions, modifications, and improvements completed since September 1989 and reported in this manual are outlined in the scope of this report in Chapter 1.

Appendix G: Notation

a Well spacing

a_{sel} Selected well spacing

c_{bl} Constant for natural landside top stratum where

$$c_{bl} = \left(\frac{k_{bl}}{k_f \, z_{bl} \, \bar{\bar{D}}} \right)^{1/2}$$

c_{br} Constant for natural riverside top stratum where

$$c_{br} = \left(\frac{k_{br}}{k_f \, z_{br} \, \bar{\bar{D}}} \right)^{1/2}$$

c_B Constant for artificial riverside blanket where

$$c_B = \left(\frac{k_B}{k_f \, z_B \, \bar{\bar{D}}} \right)^{1/2}$$

c_{Bb} Constant for riverside blanket and natural riverside top stratum where

$$c_{Bb} = \left(\frac{k_{Bb}}{k_f \, z_{Bb} \, \bar{\bar{D}}} \right)^{1/2}$$

C_w Lane's creep ratio

d Thickness of layered pervious substratum

d_n Thickness of individual layer in pervious substratum

d_c Depth of cutoff

d'_c Transformed depth of cutoff

D Thickness of single layered pervious foundation

$\bar{D}, d'$ Transformed thickness of pervious substratum

D_p Inside diameter of well screen and riser pipe

f Resistance coefficient for flow in pipe

F_t Transformation factor

FS Factor of safety

h Friction head loss in 100 ft of pipe

h_a Allowable (net) head beneath landside top stratum

h_b Height of berm intercept on levee landside slope = $m_1 t/(m_1 - m_2)$

h_e Head loss through filter and screen

h_f Friction loss along riser and screen

h_o Hydrostatic head beneath top stratum at landside toe of levee without seepage control measures, or hydrostatic head beneath top stratum at landside toe of levee with berm

h_v Velocity head loss

H Net head on levee, or height of flood stage above average low ground surface or tailwater landward of levee

H_{av} Gross average head in plane of wells

H_e Entrance head loss through filter and well screen

H_{el} Height of well top above tailwater

H_m Head midway between wells

H_r Friction head loss in riser pipe

H_s Friction head loss in well screen

H_w Total hydraulic head loss in well

H_v Velocity head loss in well

i Upward gradient at landside toe, h_o/z_t

i_a Allowable upward gradient at landside toe of levee for riverside blanket design

i_{cr} Critical gradient through landside top stratum

i_1 Allowable upward gradient at landside toe of berm

i_o Allowable upward gradient at landside toe of levee

I Hydraulic gradient

J Percent reduction in seepage flow beneath levee

k Coefficient of permeability

$\bar{k}$ Transformed permeability $(k_{fh} \times k_{fv})^{1/2}$

k_b Blanket permeability

k_{bl} Permeability of landside top stratum

k_{br} Permeability of riverside top stratum

k_B Permeability of artificial riverside blanket

k_{Bb} Average combined vertical permeability of riverside natural top stratum and artificial blanket

k_f Permeability of pervious foundation

k_{fh} Horizontal permeability of pervious stratum

k_{fv} Vertical permeability of pervious stratum

k_{hn} Horizontal permeability of individual stratum

k_{vn} Vertical permeability of individual stratum

k_t Vertical permeability of landside seepage berm

L_1 Riverward extent of top stratum measured from riverside levee toe

L_2 Base width of levee and impervious berm, if present

L_3 Landward extent of top stratum measured from landside levee toe

L_4 Extra entrance length for Rock Island berm design = 0.44 D

L_B Width of riverside borrow pit and/or required length of artificial riverside blanket

L_{Bq} Width of riverside blanket required to reduce seepage

m_1 Average landside slope of levee

m_2 Berm slope

m_3 Slope at berm toe, or toe of triangular riverside blanket

m_4 Average riverside slope of levee

m_5 Slope of triangular riverside blanket

M Slope of hydraulic grade line

N Number of layers in pervious foundation

P Effective penetration of well screen into pervious foundation

Q_s Total amount of seepage passing beneath levee per 100 ft of levee station

Q_w Well discharge

Q_{wdes} Desired well discharge to achieve flow reduction J

r_w Effective radius of well

R_e Reynolds number

s Distance from the landside toe of the levee to the point of effective seepage entry, $x_1 + L_2$

t Required thickness of landside seepage berm at toe of levee

V_B Volume of berm per 100 ft of levee station

V_{RB} Volume of riverside blanket per 100 ft of levee station

$\bar{w}$ Actual length of well screen in pervious foundation

x_1 Effective length of riverside blanket

x_3 Distance from landside levee toe to effective seepage exit

x_r Required effective length of riverside blanket to reduce hydrostatic pressure

x_{rq} Required effective length of riverside blanket to reduce seepage

X Berm width

X_I Width of impervious berm

X_{SP} Width of semipervious berm

X_S Width of sand berm

X_P Width of pervious berm with collector pipe

z Total thickness of top stratum

z_{bl} Transformed thickness of landside top stratum

z_{br} Transformed thickness of riverside top stratum

z_B Thickness of artificial riverside blanket

z_{Bb} Total effective thickness of natural and artificial riverside top stratum

z_l Total thickness of landside top stratum

z_{ln} Thicknesses of individual layers (n layers) in landside top strata

z_r Total thickness of riverside top strata

z_{rn} Thicknesses of individual layers (n layers) in riverside top strata

z_t Critical thickness of top stratum

$\$$ Shape factor of generalized cross section of the levee and foundation

γ' Submerged unit weight of landside top stratum soil

ε Coefficient of pipe roughness

Θ_{av} Average uplift factor

Θ_m Midpoint uplift factor

ν Viscosity of water at a given temperature

ϕ_m Form factor used with method of fragments

Supplemental Computer Notations

BF	Backfill
DD	Transformed thickness of previous substratum
DRP	Drilling through previous foundation cost
DRT	Drilling through top stratum cost
FL	Filter cost
FSB	Factor of safety for berm analysis
FSW	Factor of safety for well analysis
IOB	Allowable gradient at landside levee toe for berm analysis
LTE	Landside toe elevation
LTO	Landside toe offset
M3B	Slope at berm toe
M3R	Slope at triangular riverside blanket toe
RP	Risen pipe cost
RTO	Riverside toe offset
SUBWT	Submerged unit weight of top stratum
WC	Well cover cost
WD	Well development cost
WS	Well screen cost
$	Shape factor

REPORT DOCUMENTATION PAGE

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1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
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LEVSEEP: Analysis Software for Levee Underseepage and Rehabilitation

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13. ABSTRACT *(Maximum 200 words)*

The computer program LEVSEEP version 3.0 is presented for use in the analysis of levee underseepage. The program is written in Microsoft QuickBASIC (TM) (Microsoft Corporation 1986), furnished as a binary executable file, LEVSEEP.EXE, designed to run on IBM (TM) and compatible personal computers under the MS DOS (Microsoft Corporation 1983) operating system, and has full-screen editing as well as graphics capabilities. This version of the program includes a two-layer analysis model for levees with a top blanket over a pervious foundation. The software calculates seepage flow and substratum pressure for either physical and geometric properties (initial conditions) or field piezometer readings; analyzes the effects of various control measures (namely, landside berms, riverside blankets, cutoffs, and relief wells); plots cross sections, piezometer data, and control measures; provides quantity and cost estimates of each of these control measure alternatives; and gives a complete summary of all calculations. The procedures for berm analysis employed within LEVSEEP reflect the current Corps

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guidance discussed in EM 1110-2-1913 (Headquarters, Department of the Army 1978). The procedures for riverside blanket analysis are as presented in TM 3-424 (U.S. Army Engineer Waterways Experiment Station 1956). Procedures for analysis of cutoffs are based on the method of fragments as presented by Harr (1962). The procedures for relief well system analysis reflect Corps guidance as presented in EM 1110-2-1913. Specific equations and procedures used for well analysis were taken from TM 3-424 and Engineer Bulletin 55-11 (Headquarters, Department of the Army 1955). The well procedure is for infinite, partially penetrating, or fully penetrating well systems under artesian flow; it does not apply to finite length systems or pumped systems. Example problems and case studies are presented in this report for instruction and verification of the computer model. Magnolia Levee, Ohio, located in the Huntington District, was selected as a case study to demonstrate the application of LEVSEEP. Results of the case studies emphasized the importance of accurate characterization of the foundation sublayers. LEVSEEP provides a convenient analysis tool that should allow designers to approximately model actual field conditions. However, flood protection is a complex system involving design, construction, maintenance, and performance evaluation of levees. The use of LEVSEEP can provide flexibility in exploring the influence of varying key analysis parameters on the predicted results. Such a flexibility can lead to reevaluation of design criteria with the benefit of reducing cost and improving safety.

14. (Concluded).

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